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Biofiltration of ethylbenzene vapours: Influence of the packing material

F.J. Álvarez-Hornos [a], C. Gabaldón [a,*], V. Martínez-Soria [a], M. Martín [b], P. Marzal [a], J.M. Penya-roja [a]

[a] Department of Chemical Engineering, University of Valencia, Dr. Moliner, 50, 46100 Burjassot, Spain

[b] Department of Hydraulic and Environmental Engineering, Polytechnic University of Valencia, Camino de Vera s/n, 46022 Valencia, Spain

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Abstract

In order to investigate suitable packing materials, a soil amendment composed of granular high mineralized peat (35% organic content) locally available has been evaluated as carrier material for biofiltration of volatile organic compounds in air by comparison with a fibrous peat (95% organic content). Both supports were tested to eliminate ethylbenzene from air streams in laboratory-scale reactors inoculated with a two-month conditioned culture. In pseudo-steady state operation, experiments at various ethylbenzene inlet loads (ILs) were carried out. Maximum elimination capacity of about 120 $g\,m^{-3}\,h^{-1}$ for an IL of 135 $g\,m^{-3}\,h^{-1}$ was obtained for the fibrous peat. The soil amendment reactor achieved a maximum elimination capacity of about 45 $g\,m^{-3}\,h^{-1}$ for an inlet load of 55 $g\,m^{-3}\,h^{-1}$. Ottengraf–van den Oever model was applied to the prediction of the performance of both biofilters. The influence of gas flow rate was also studied: the fibrous peat reactor kept near complete removal efficiency for empty bed residence times greater than 1 min. For the soil amendment reactor, an empty bed residence time greater than 2 min was needed to achieve adequate removal efficiency. Concentration profiles along the biofilter were also compared: elimination occurred in the whole fibrous peat biofilter, while in the soil amendment reactor the biodegradation only occurred in the first 65% part of the biofilter. Results indicated that soil amendment material, previously selected to increase the organic content, would have potential application as biofilter carrier to treat moderate VOC inlet loads.

Keywords: Air control pollution; Biofiltration; Ethylbenzene; Volatile organic compounds

1. Introduction

As a consequence of the more and more stringent environmental regulations directed to emissions of volatile organic compounds (VOCs) from industrial sources, treatment technologies are demanded. Conventional physical and chemical VOCs removal process are expensive, require complex equipment and/or generate hazardous residues, so bioremediation, and particularly biofiltration, is turning into a sustainable alternative for VOCs removal. Biofiltration is a low cost and non-generating hazardous residue, and shows an especial interest for its application in small industrial plants with low concentrations in the waste gas.

Initially, biofiltration was used to remove odorous compounds such as ammonia, mercaptans and hydrogen sulphide from air (Smet et al., 1998). In the last years, this technology has been extended to the removal of VOCs, and several studies have reported effective elimination of aromatic VOCs, such as ethylbenzene (Kennes et al., 1996; Sorial et al., 1997; Quinlan et al., 1999) but only for dilute air streams (<0.5 $g\,m^{-3}$). Jorio et al. (1998) indicated that for higher concentrations of aromatics, biofilter performance needs further improvement in order to meet environmental requirements.

The nature of biofilter medium is a key factor for a successful application of biofilters, affecting both, the removal

* Corresponding author. Tel.: +34 963543331; fax: +34 963544898.
E-mail address: carmen.gabaldon@uv.es (C. Gabaldón).

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performance related to bacterial activity, and the cost related to pressure drop and bed material replacement. Natural materials such as peat, compost, soil, activated carbon and others have been used as filter media (Devinny et al., 1999; Malhautier et al., 2005; Delhoménie and Heitz, 2005). Nevertheless, just a few studies have been carried out comparing different materials. Aizpuru et al. (2003) have studied the biofiltration of a complex mixture of VOC using both a granular peat and a granular activated carbon. The reported removal efficiency of the peat was higher and differences in the VOC profiles were observed comparing both packing materials. Ortiz et al. (2003) compared the behaviour of different organic and inorganic supports on the biofiltration of benzene, toluene and xylene vapours. The greater removal efficiencies were obtained with a mixture of vermiculite and activated carbon.

In order to select a suitable low-cost effective packing material, the performance of laboratory biofilters using two supports was investigated to treat air polluted with high concentrations of ethylbenzene. Ethylbenzene was selected as representative of monoaromatic hydrocarbon compounds that are moderately biodegradable. The two supports studied as biofilter media were a natural material cheap and locally abundant in deposits, containing peat, (named "soil amendment") and a commercial fibrous peat from Poland (named "fibrous peat"). A spontaneous ethylbenzene-degrading microbial population originated from sludge of municipal wastewater treatment plant was used as inoculum. In this work, the effects of operating conditions such as influent ethylbenzene load and empty bed residence time (EBRT) were studied in order to attain the influence of the packing material upon the removal efficiency.

2. Methods

2.1. Packing material and inoculum preparation

The selected commercial fibrous peat (Pro Eco Ambiente, Spain) has been shown effective to treat monoaromatic solvent vapours (Gabaldón et al., 2004) and then was chosen as a reference packing medium. The alternative support was commercial organic sediment supplied by Infertosa (Spain). It is obtained by mixing a high mineralized peat extracted from the *Torreblanca* deposit located in Castellón (Spain) with inorganic chemicals to use it as a commercial amendment of soil. In this study, the commercial amendment was used. The material was sieved to reject particles with a diameter less than 3 mm. The characteristics of the packing materials are given in Table 1. Chemical composition was determined using an elemental analyzer, organic content was determined by calcination at 550 °C, and specific surface area by the nitrogen adsorption–desorption method. This alternative support is a low-cost material (80 €/m^3) comparing with the fibrous peat (150 €/m^3). If results indicate a potential application of the material used in this study, Infertosa could select material with an organic content up to 53% with a specific surface area of about 5 $m^2\,g^{-1}$.

Table 1
Physical and chemical properties of packing materials

	Fibrous peat	Soil amendment
Chemical composition (%)		
C	48.5	17.0
H	5.8	1.8
O	40.0	16.3
S	0.1	1.1
N	0.6	0.8
Organic content (%)	95	35
Bulk density (kg m^{-3})	133	900
Average particle diameter (mm)		4.9 (1.2 std deviation)
Specific surface area ($m^2\,g^{-1}$)	13.4	1.3
Water holding capacity (% by weight)	88.0	61.2
pH	4.8	6.2

Fibrous peat was acidic. Before introducing it into the column, pH adjustment was done until neutral pH by using dilute sodium hydroxide solution. No pH adjustment was required for the soil amendment. The inoculum was obtained from a two-month acclimatised culture seeded with activated sludge from the secondary clarifier of Carraixet Wastewater Treatment Plant located in Alboraya (Spain). Carraixet plant receives urban sewage from Alboraya town and pollutants from the Alboraya industrial site. Two litres of the concentrated sludge were placed in an aerated batch reactor and diluted with 1 L of nutrient solution containing N and P (3.84 g L^{-1} K_2HPO_4, 1.94 g L^{-1} KH_2PO_4, 3.00 g L^{-1} NH_4Cl, pH 6.97). Vitamins and trace minerals were added by diluting 3 g of Supradyn® (Roche). The reactor was continuously fed with ethylbenzene at a rate of 1 mL h^{-1} for a minimum period of 8 weeks. Suspended solids concentration and oxygen uptake rate were controlled twice a week along with periodical purge of excess sludge to get a stable operation. Values of oxygen uptake rate of 1000–1500 mg L^{-1} day^{-1}, for amounts of suspended solids between 2000 and 3000 mg L^{-1}, were considered as indicative of a suitable performance of the suspended culture. By mixing 1 L of this conditioned sludge with the filter material the biofilter seeding was performed.

2.2. Experimental setup and monitoring of biofilters

The ethylbenzene biodegradation was carried out in laboratory-scale biofilters (Fig. 1) made of methacrylate, with a total height of 97 cm and an internal diameter of 13.6 cm. A 10 cm head space was used for the waste gas inlet and for nutrient feed, while a 10 cm bottom space was used for the treated air outlet and leachate. The biofilter was equipped with five sampling ports to measure VOC concentrations, located at 0 (inlet port), 25, 50, 75, and 97 (outlet port) cm of column height. Additional ports located at 20, 40, 60 and 80 cm were used for temperature measurement and to recover bed particles for humidity analyses. Peat