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Evaluating the impact of water supply strategies on *p*-xylene biodegradation performance in an organic media-based biofilter

G. Gallastegui [a], R. Muñoz [b], A. Barona [a], G. Ibarra-Berastegi [c], N. Rojo [a], A. Elías [a,*]

[a] Department of Chemical and Environmental Engineering, Engineering Faculty, University of the Basque Country, Alda Urquijo s/n, 48013 Bilbao, Spain
[b] Department of Chemical Engineering and Environmental Technology, Valladolid University, Dr. Mergelina s/n, 47011 Valladolid, Spain
[c] Department of Nuclear Engineering and Fluid Mechanics, Engineering Faculty, University of the Basque Country, Alda Urquijo s/n, 48013 Bilbao, Spain

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ABSTRACT

The influence of water irrigation on both the long-term and short-term performance of p-xylene biodegradation under several organic loading scenarios was investigated using an organic packing material composed of pelletised sawdust and pig manure. Process operation in a modular biofilter, using no external water supply other than the moisture from the saturated inlet air stream, showed poor p-xylene abatement efficiencies (≈33 ± 7%), while sustained irrigation every 25 days rendered a high removal efficiency (RE) for a critical loading rate of 120 g m^{-3} h^{-1}. Periodic profiles of removal efficiency, temperature and moisture content were recorded throughout the biofilter column subsequent to each biofilter irrigation. Hence, higher p-xylene biodegradation rates were always initially recorded in the upper module, which resulted in a subsequent increase in temperature and a decrease in moisture content. This decrease in the moisture content in the upper module resulted in a higher removal rate in the middle module, while the moisture level in the lower module steadily increased as a result of water condensation. Based on these results, mass balance calculations performed using measured bed temperatures and relatively humidity values were successfully used to account for water balances in the biofilter over time. Finally, the absence of bed compaction after 550 days of continuous operation confirmed the suitability of this organic material for biofiltration processes.

1. Introduction

Biofiltration is now one of the most cost-effective and sustainable off-gas treatment technologies due to its minimal energy requirements and low environmental impact [1,2]. Based on its simple operation and high removal efficiencies for both hydrophilic and hydrophobic volatile pollutants, biofiltration is the most popular biotechnologies for the treatment of odours and industrial volatile organic compounds (VOCs) [3,4].

Since their introduction in the 1960s, a considerable amount of research has been conducted to elucidate the mechanisms underlying pollutant removal in biofilters and to enhance their robustness in order to increase their acceptance within the industrial community [5,6]. Most studies have focused on the optimization of relevant factors such as the nature of the packing material, moisture content, biomass growth control, pH, nutrient availability, etc. [7–10]. Due to their biological basis, the control of moisture content (water activity) in biofilters is a key operating parameter determining process performance [6]. As a matter of fact, an inefficient control of the moisture content has been reported as the cause of 75% of biofilter failures [11].

Water activity is responsible for the type (bacteria vs. fungi) and level of activity of the microbial community present, and determines the long-term structural stability of the packed bed (compaction, formation of anaerobic zones or preferential pathways, etc.) [12]. However, the control of moisture content in the packing material is compulsory and complex, as a large number of factors need to be considered: the moisture content of the gas stream entering the biofilter, the frequency and flow of external irrigation, the exothermicity of pollutant mineralization, the organic nature of the packing material, the biomass distribution profile within the biofilter and the water retention capacity of each packing material [3,13]. Water activity in biofiltration systems must therefore be carefully studied on a case-by-case basis in order to ensure consistent VOC and odour treatment efficiencies, especially when using novel organic packing materials. However, despite the importance of this issue, there are few published studies devoted to understanding and further optimizing the temporal and spatial distribution of moisture content in biofilters [11,13,14].

This work focuses the influence of different irrigation and operating strategies on the performance of p-xylene abatement using an organic packing material composed of pelletised sawdust and pig manure. Special attention was given to the interdependence

* Corresponding author. Tel.: +34 94 601 4087; fax: +34 94 601 4179.
E-mail address: ana.elias@ehu.es (A. Elías).

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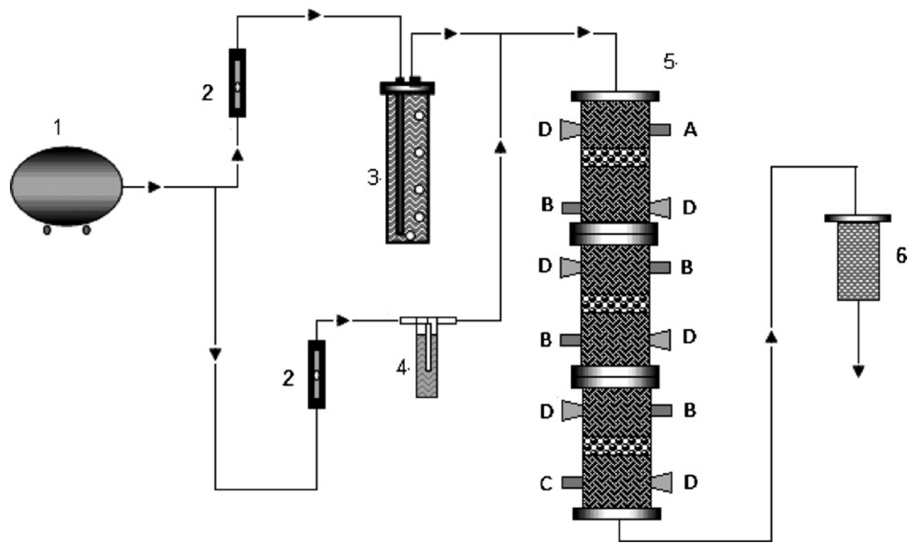

Fig. 1. Diagram of the biofiltration system: 1, air-compressor; 2, flow meter; 3, humidification chamber; 4, *p*-xylene evaporator; 5, modular biofilter; 6, active carbon chamber; A (inlet gas sampling valve); B (inter-module gas sampling valve); C (outlet gas sampling valve) and D (temperature and air relative humidity measurement ports).

between moisture content and pollutant removal efficiency by carefully monitoring the timeline of the profiles of both parameters throughout the biofilter column. p-Xylene, was used as a model VOC due to its widespread use in the ever-increasing production of polyethylene terephthalate [15].

2. Materials and methods

2.1. Inoculum preparation

Despite the indigenous microflora present in the packing material used in this work had previously shown a good capacity for degrading H_2S [16], it was not capable of mineralizing p-xylene. Thus, an aerobic activated sludge collected at the wastewater treatment plant in Muskiz (Bizkaia, Spain) was used as inoculum for p-xylene biodegradation. Initially, the activated sludge was continuously exposed for 30 days in a stirred tank bioreactor to a p-xylene-laden air at an aeration rate of 0.4 vvm (air volume per unit of liquid volume per minute) and at concentrations ranging from 50 to 100 ppm_v. The measurement of p-xylene degradation rate in batch assays confirmed the acclimatization of the microbial population present in the liquid phase. This procedure has already been explained in a previous work [17].

2.2. Biofilter setup

The biofiltration system consisted of 3 PVC modules (Fig. 1). The packed bed was divided into the three identical sections with a total volume of 4.5 L. The packing material selected in this work was supplied by SLIR S.L (Specialised Engineering in Recycling Agricultural Residues) and its commercial name was ABONLIR. This material was made up of composted pig manure and sawdust, and the pellets were manufactured by mechanical compression without chemical addition. The compost was stored in sealed plastic bags at room temperature to maintain its original moisture content. Table 1 summarizes the main characteristics of the packing material [16]. The biofilter was initially irrigated with an activated sludge acclimated according to the procedure published by Elías et al. [17] and it was operated in a downflow configuration at $23 \pm 2\,^{\circ}C$. The flow of p-xylene-contaminated air was added from the top of the biofilter at a flow rate of 1–1.5 $L\,min^{-1}$ (corresponding to an empty bed residence time ranging from 180 to 270 s) and the contaminated flow was generated by mixing a p-xylene-saturated air stream with a humidified p-xylene-free air stream in different proportions. The non-humidified fraction of air used for p-xylene saturation was a minor fraction of the whole influent air flow and did not significantly impact the moisture of the contaminated air stream entering the biofilter. Indeed, the relative humidity of the contaminated air at the biofilter inlet remained always higher than 98%. An activated carbon filter was also included in the experimental setup, being fitted to the bioreactor outlet in order to mitigate the environmental impact of the non-degraded contaminant. The biofilter was equipped with several gas sampling valves to monitor the inlet, outlet and inter-module p-xylene and CO_2 concentrations. Additionally, it was also provided with several ports located throughout the three PVC modules for measuring the temperature and relative humidity content of the air.

2.3. Influence of water irrigation on the long-term performance of p-xylene biodegradation

The system was initially operated for 260 days with no further irrigation, as water was supplied solely via the saturated inlet air stream (relative humidity ≥98%) (dry period). From days 260 to 550 (wet period), each of the 3 modules was individually irrigated every 25 days with 400 mL of mineral salt medium [18], in order to avoid drip of water from the top section to the middle and bottom sections.

Table 1
Physical–chemical properties of the packing material used in the modular biofiltration unit [16].

Organic matter (%)[a]	40.0
Total nitrogen (%)	1.4
P_2O_5 (%)	1.1
K_2O (%)	1.5
Total S (%)	3.3
pH	6.5–7.5
Mean length (mm)	10.7
Mean radius (mm)	6.1
Bulk density ($g\,cm^{-3}$)	1.3
Real density ($g\,cm^{-3}$)	2.3
B.E.T. (N_2) surface area ($m^2\,g^{-1}$)	12.06 ± 0.09
BJH adsorption average pore diameter (Å)	145
Macropore volume in the pellets (%)	89.42
Micropore area ($d < 20$ Å) ($m^2\,g^{-1}$)	0.3
Initial moisture content (%)	25.2

[a] Value provided by the manufacturer.