# INFLUENCE OF GAS FLOW RATE AND INLET LOAD ON THE REMOVAL OF ETHYLBENZENE VAPORS FROM AIR IN A PEAT BIOFILTER

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## ABSTRACT

Air biofiltration has been shown as a clean, low-cost competitive alternative to the physico-chemical treatment technologies to remove volatile organic compounds (VOCs) from industrial air emissions. In order to investigate the performance of this growing technology, two identical biofiltration units at laboratory scale were operated for continuous removal of ethylbenzene vapors over 3 months. Commercially conditioned peat was used as support material. At star-up, the biofilters were inoculated with a two-months conditioned culture seeded with activated sludge from an industrial wastewater treatment plant. The moisture content of the filter material was adjusted to approximately 80-85% (wet basis). Nutrients were added periodically to the medium. Temperature was kept on 24-28 ºC. The influence of ethylbenzene inlet concentration and gas flow rate on the biofilter performance were studied and nearly complete removals were obtained. In the best performing biofilter, ethylbenzene inlet concentration was raised stepwise to 4.8 $gm^{-3}$, using a constant flow rate of 0.4 $m^3h^{-1}$ (2 minutes of empty bed residence time). Maximum removal efficiency was found in 117 $gm^{-3}h^{-1}$, and near complete removal of ethylbenzene was reached for inlet loads up to 100 $gm^{-3}h^{-1}$. Inlet gas flow rate was varied from 0.4 $m^3h^{-1}$ to 2.6 $m^3h^{-1}$ showing that empty bed residence times < 60 s lowered the removal efficiency. In the other biofilter, 4 min of empty bed residence time was needed to reach satisfactory elimination capacities, showing that greater contact times allow to treat inlet concentrations of ethylbenzene up to 5.6 $gm^{-3}$.

## INTRODUCTION

As a consequence of the more and more stringent environmental regulations directed to lower emissions of volatile organic compounds (VOCs) from industrial sources, together with the fact that conventional physical and chemical VOCs removal processes are expensive, require complex and/or generate hazardous residues, bioremediation, and particularly biofiltration, is turning into an attractive alternative for VOCs removal, of low cost and non-hazardous residues, especially in small industrial plants with low concentrations in the waste gas.

Initially, biofiltration was used to remove odorous compounds and inorganic substances such as ammonia, mercaptans and hydrogen sulfide from air [1]. In the last years, this technology has been extended to removal of VOCs, and several studies have been reported for effective elimination of aromatic VOCs, such as ethylbenzene [2]-[4], but only for dilute air streams (<0.5 g $m^{-3}$) [5], suggesting that for higher concentrations of aromatics biofilter performance needs further improvement in order to meet environmental requirements.

The performance of two laboratory-plants using peat material has been investigated to treat air polluted with high concentrations of ethylbenzene over a total period of three months. A

spontaneous ethylbenzene-degrading microbial population originating from sludge of municipal wastewater treatment plant was used as inoculum. In this work, the effects of operating conditions such as ethylbenzene influent concentration and empty bed residence time have been studied in order to evaluate the maximum elimination capacity and the optimal operating conditions.

## MATERIALS AND METHODS

The procedure for obtaining ethylbenzene acclimated inoculum has been described elsewhere [5]. Peat (ProEco Medioambiente, Spain) was used as filter material. The peat was acidic, so pH adjustment until neutral pH was made by using dilute sodium hydroxide solution. As peat is naturally rather nutrient-poor material for bacterial growth, 500 mL of nutrient solution and pH buffer (3.84 g/L $K_2HPO_4$, 1.94 g/L $KH_2PO_4$, 3 g/L $NH_4Cl$, pH = 6.97) were added to the biofilters about every four days.

The ethylbenzene biodegradation was carried out in two identical laboratory-scale biofilters operated in parallel (fig. 1). Each biofilter was made of methacriltate, with a total length 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 for the treated air outlet and leachate. Each biofilter was equipped with five sampling ports to measure VOC concentrations, located at 0 (inlet port), 25, 50, 75, and 95 (outlet port) cm of column length.

Compressed, filtered and dried air was passed through the humidifier to assure a relative humidity value of at least 90%. The empty bed residence time (EBRT) was adjusted by using mass flow controllers (Bronkhorst Hi-Tec). The suitable flow of ethylbenzene was introduced to the air stream by using a syringe pump (New Era, infusion/withdraw NE 1800 model) and then, the contaminated air was flowed downwards into the bed.

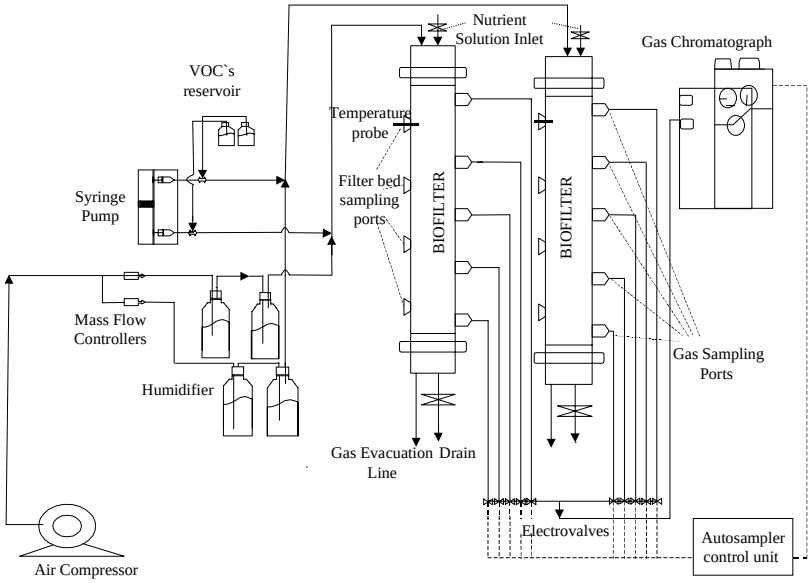


Figure1. The schematic diagram of the biofilter system.

Temperature, pH of the leachates and pressure drop were monitored daily for both biofilters. Temperature was kept between 24 and 28 ºC for the duration of the study. The water content

of the filter material was measured weekly, and the peat was kept at constant humidity of about 80% (wet basis) by periodically pouring on top of the biofilters the nutrient solution.
The concentration of ethylbenzene in the air stream was measured by using a previously calibrated gas chromatograph (CE Instruments, GC 8000 model) equipped with a 2.5 mL automated gas valve injection system and a flame ionization detector.

## RESULTS AND DISCUSSION

The operation parameters of biofilter 1 and 2 (table 1), were changed in order to study the effect of load and concentration of ethylbenzene inlet. Experiments were carried out in three different stages as shown in figure 2.

| | Stage | Days | EBRT* (s) | Inlet concentration ($gm^{-3}$) | Inlet load ($gm^{-3}h^{-1}$) |
|---|---|---|---|---|---|
| Biofilter 1 | I | 1-20 | 45 | 0.2-0.7 | 20-56 |
| | II | 21-70 | 90 | 0.08-2.3 | 3-90 |
| | III | 71-90 | 70-250 | 0.5-5.6 | 25-75 |
| Biofilter 2 | I | 1-24 | 115 | 0.2-2.5 | 9-70 |
| | II | 25-49 | 18-115 | 0.09-0.7 | 20 |
| | III | 50-70 | 115 | 0.5-5.0 | 34-135 |

Table 1. The operating conditions of biofilters. *EBRT: Empty Bed gas Residence Time

At the beginning of the experiments, stage I, elimination capacity stay >95 % up to inlet concentrations of 0.7 $gm^{-3}$ for biofilter 1 and 2.5 $gm^{-3}$ for biofilter 2. These high efficiencies from the first day of operation are evidence of the right development of the inoculum.

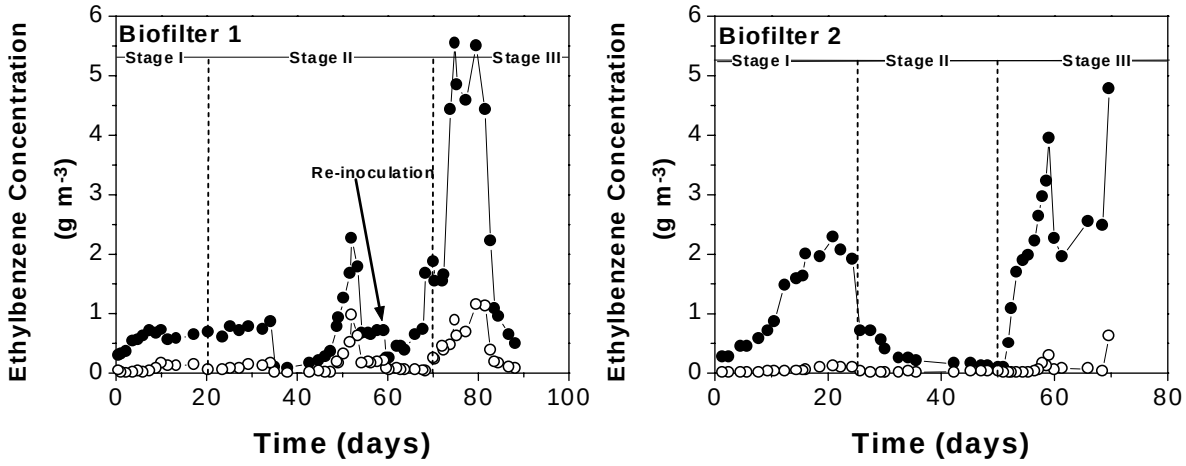


Figure 2. Performance of Biofilters. Inlet (●) and outlet (○) ethylbenzene concentrations.

In Biofilter 1, stage II, after some days of operation a decrease in efficiency (deactivation) was observed, and it was necessary to re-inoculate the biofilter. After the re-inoculation Biofilter 1 recuperated its initial efficiency, as can be shown in figure 3, since the first

moment, showing a very interesting method to recover the activity in biofilter and then resolve some operational and performance problems in the use of biofilters.

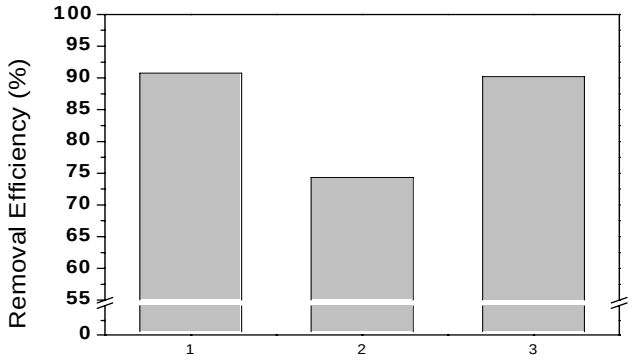


Figure 3. Removal efficiency of stage II Biofilter 1 at the same operation conditions: EBRT= 90 s, ethylbenzene concentration 0.6 $gm^{-3}$. 1) day 24, before deactivation, 2) day 56, deactivation period and 3) day 66, after the reinoculation.

One of the most important parameters in the biofiltration process is the pollutant concentration that can be removed efficiently. It is well known that highly concentrated emissions of moderated or poorly biodegradable pollutants may produce negative effects on the metabolic activity of the microbial population. The highest experimental ethylbenzene inlet concentrations were used in stage III in both biofilters. In case of Biofilter 1, using a low gas flow rate (EBRT=250 s), concentration up to 5.6 $gm^{-3}$ have reached satisfactory elimination efficiencies. For example, for concentrations of 5.0 and 5.6 $gm^{-3}$, higher than those usually reported in literature [2]-[4], the removal efficiencies obtained were about 87 and 83 %. In case of Biofilter 2, with a higher gas flow rate (EBRT= 120 s) at a maximum ethylbenzene concentration of 4.9 $gm^{-3}$ the removal efficiency was about 87 %. Comparing both biofilters at similar conditions, that is, EBRT= 120-130 s and Ethylbenzene inlet concentration = 1.8 $gm^{-3}$, the removal efficiencies were 77% and 99% for Biofilter 1 and 2, respectively, denoting the best performance of biofilter 2. Similar conclusion can be obtained when removal capacity of both biofiofilters is compared (figure 4).

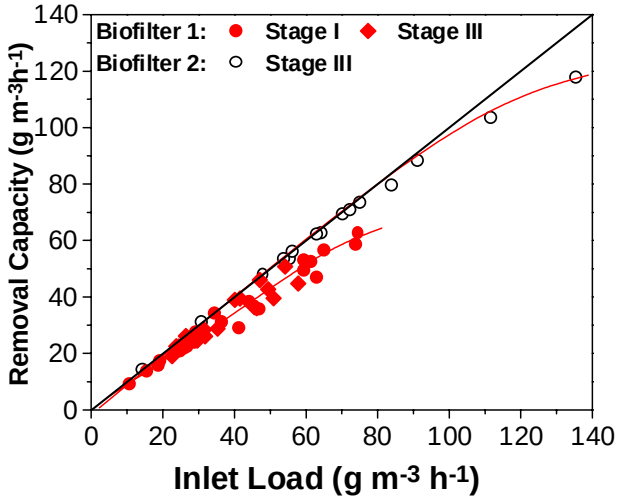


Figure 4. Removal capacity versus ethylbenzene inlet load.

As can be seen in figure 4, the removal capacity for Biofilter 2 is considerably higher than obtained for Biofilter 1. The maximum removal capacity for Biofilter 1 is about 70 $gm^{-3}h^{-1}$, which is usual value described in literature[2] and [6], whereas in Biofilter 2, for a inlet load of 100 $gm^{-3}h^{-1}$ a removal efficiency of almost 100% was obtained, and the maximum removal capacity was found in 117 $gm^{-3}h^{-1}$, what is slightly higher than the maximum value reported [7]. The different performance of biofilters could be ascribed mainly to unlike textural properties and different flow pattern distribution (channeling , by-passing, etc.). Nevertheless, a worse biomass distribution in Biofilter 1 can not be rejected as a reason for explaining the divergence between biofilters.

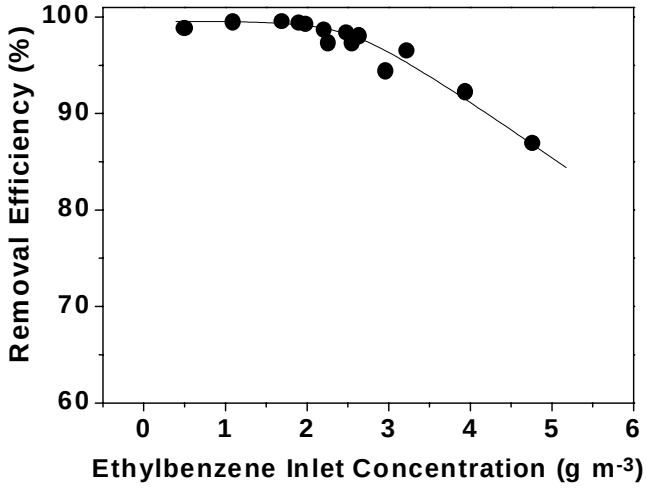


Figure 5. Removal efficiency of ethylbenzene vs. ethylbenzene inlet concentration for empty bed gas residence time of about two minutes. Biofilter II, stage III.

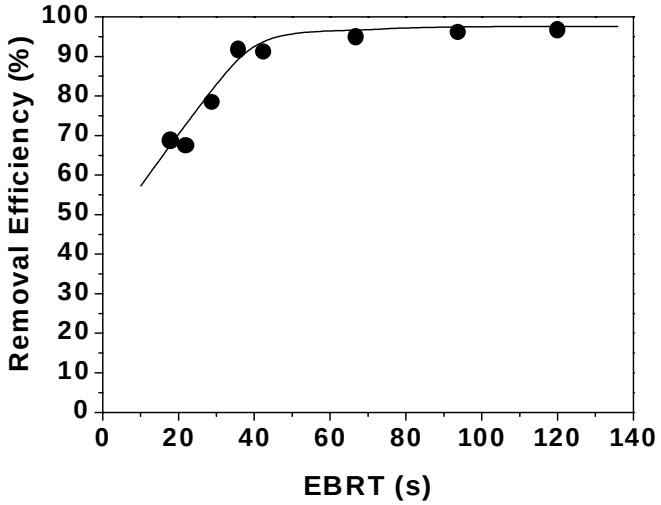


Figure 6. Removal efficiency of ethylbenzene vs. empty bed gas residence time (EBTR) at constant ethylbenzene inlet load (20 $gm^{-3}h^{-1}$). Biofilter II, stage II.

In the present work the combined effect of ethylbenzene concentration and the gas flow rate has been investigated in Biofilter 2, stages II and III. Figure 5 presents the removal efficiency versus ethylbenzene concentration at a constant gas flow rate (0.4 $m^3h^{-1}$), showing an almost completed removal for concentration lower than 2.5 $gm^{-3}$ and decreases from 100% to 85% as the inlet concentration increases to 5.0 $gm^{-3}$. The highest values of elimination capacity (>100 $gm^{-3}h^{-1}$) have been obtained in these last experiments. Figure 6 shows the removal efficiency as a function of the gas flow rate at a constant ethylbenzene inlet load (20 $gm^{-3}h^{-1}$). Almost a whole ethylbenzene elimination is obtained for gas flow rates lower than 1.0 $m^3h^{-1}$, that is EBRT higher than 50 seconds, and lowers, almost linearly, until a 65 % of removal efficiency for residence times of 20 seconds.

## CONCLUSION

Two laboratory-scale peat biofilters were operated in parallel for a continuous period of 3 months to remove ethylbenzene vapors showing a suitable performance. Differences between the achievement of both biofilters were obtained. After a re-inoculation the initial activity of a 'deactivated' biofilter could be recovered. High ethylbenzene concentration values (>5.0 $gm^{-3}$) has been adequately treated, and very high values of elimination capacity have been obtained (117 $gm^{-3}h^{-1}$). Experimental results revealed that removal efficiency was higher for smaller gas flow rate and for smaller ethylbenzene concentrations.

## ACKNOWLEDGMENTS

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