Styrene degradation in perlite biofilter: The overall performance characteristics and dynamic response

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ABSTRACT

Styrene's degradation in a perlite biofilter including the long-term operation, dynamic response to step-changes in inlet concentration and non-use periods were tested. The study was performed in a bench-scale biofilter with ID 100 mm and a bed height of 1 m. Perlite with a particle size of 2 – 4 mm was used as a packing material. An enrichment mixed culture was immobilized on the packing. The inoculum was obtained from a styrene biofilter.

Two different loading conditions were tested: (1) Loading with a high inlet concentration and a high residence time. (2) Loading with a low inlet concentration and the low residence time. Both conditions are common in industrial practice. The dynamic response to a repeated step-change in the inlet concentration (from 50 to 200 $mg.m^{-3}$) was tested. The dynamic behaviour of the re-starting period after varying periods of non-use was also investigated.

The results demonstrate a high biofilter stability under extreme loading conditions and also during the step-changes of the inlet concentration. The non-use periods tested had almost no effect on the biofilter performance. The maximum outlet concentration after the restarting of the load was 4 $mg.m^{-3}$, when a 95 hours idle period was used. After shorter idle periods, the outlet styrene concentrations did not exceed 0.6 $mg.m^{-3}$.

1 INTRODUCTION

Styrene is a toxic volatile liquid with a specific odor witch is commonly used in industry. Styrene monomer is used for the production of polystyrene, styrene copolymers and polystyrene resins (Paca and Koutsky 2000; Bina *et al.*, 2004). Production and processing of styrene are main sources of styrene pollution. Another source of contamination is the incineration of styrene polymers.

Since styrene is a toxic compound, it is necessary to reduce its emissions. In addition, by reason of very low odor threshold (0.1 ppm) and characteristic uncomfortable odor, styrene can be defined like odor emission. Styrene-containing gases may be biologically treated in biofilters (Paca and Koutsky, 2000; Bina *et al.*, 2004; Cox *et al.*, 1997) of trickling filters (Webster *et al.*, 1999; Sorial *et al.*, 1998).

The object of the study is to test long-term biofilter stability under conditions which are common in industrial usage, such as sudden changes of inlet concentration, periods of non-use and different loading conditions.

2 MATERIALS AND METHODS

2.1 Microorganisms and cultivation

A biofilter was inoculated with enrichment mixed culture which was isolated from biofilter degrading styrene. The cells were cultivated in a mineral medium of the following composition ($g.L^{-1}$): K_2HPO_4 4.3; KH_2PO_4 3.4; KNO_2 2; $MgCl_2$ 0.34; $MgCl_2$ $0.7.10^{-3}$; $FeSO_4$ $0.6.10^{-3}$; Na_2MoO_4 $1.7.10^{-3}$. The inoculum was achieved after 7 days cultivation in modified Erlenmayer flasks on a rotary shaker at 26 °C with gasoline vapor as the sole carbon and energy source. pH of the medium was 7.0.

2.2 Experimental setup

A schematic diagram of the biofilter system is shown in Figure 1. The biofilter was made of glass with an internal diameter of 100 mm and a bed height of 1 m. The packing material was perlite with a grain size 1-3 mm and a porosity of 0.1027. Biofilter operating conditions were: up flow mode, temperature 21 – 23 °C, mineral medium added two times a week.

2.3 Analytical methods

The styrene concentration in the gas phase was determined using an Agilent 6890 N gas chromatograph equipped with an ultra alloy-5 (5 % phenylmethylsilicone) capillary column 15 m in length, inner diameter of 0.53 mm, and film thickness of 1.5 μm (Quadrex Corp., UA5 - 30V - 1.5 F, New Haven, CT). The carrier gas was argon at a flow rate of 5 $ml.min^{-1}$. The detection was carried out with a flame ionization

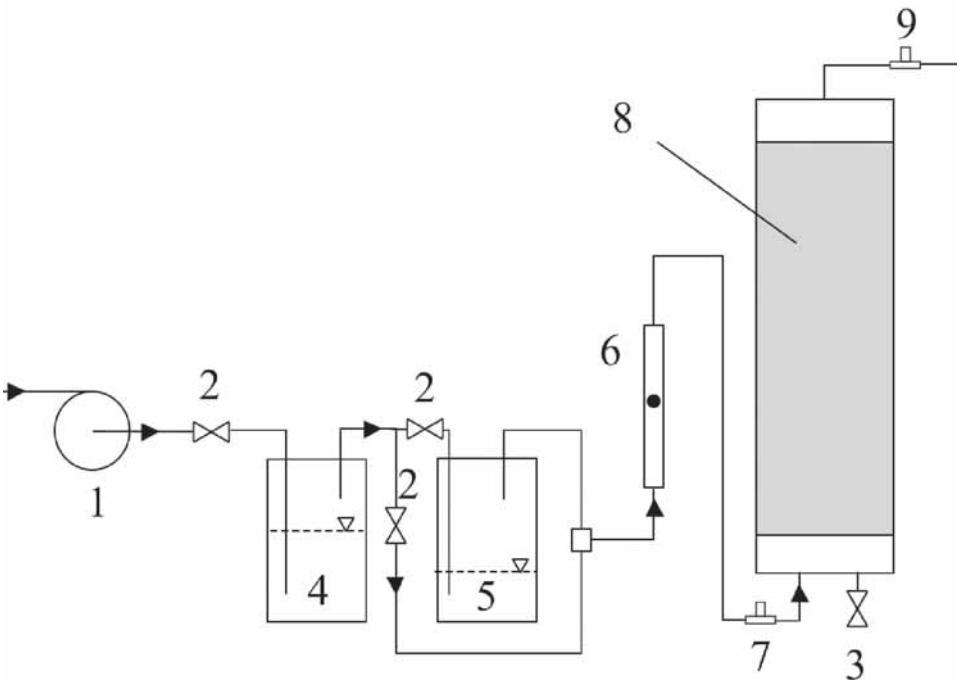

Figure 1. 1 - blower, 2 – needle valve for flow rate control, 3 – valve for leachate, 4 – humidification vessel, 5 – styren suplying to air, 6 – rotameter, 7 – inlet sampling ports, 8 – packing, 9 – outlet sampling port

detector (FID) with hydrogen and air at flow rates of 30 ml.min^{-1} and 320 ml.min^{-1}, respectively. Operating conditions were: inlet temperature, 200 °C; oven temperature, 150 °C; FID temperature, 250 °C.

2.4 Calculations

Performance parameters of the biofilter - empty bed residence time (EBRT), removal efficiency (RE), elimination capacity (EC) and organic load (OL) - were calculated as follows:

$$OL = C_{in} \cdot \frac{Q}{V_b} \qquad \left(g \cdot m^{-3} \cdot h^{-1}\right)$$

$$EBRT = \frac{V_b}{Q} \qquad (h)$$

$$EC = \left(C_{in} - C_{out}\right) \cdot \frac{Q}{V_b} \qquad \left(g \cdot m^{-3} \cdot h^{-1}\right)$$

$$RE = \frac{C_{in} - C_{out}}{C_{in}} \cdot 100 \qquad (\%)$$

where C_{in}, C_{out} are inlet and outlet concentrations ($g.m^{-3}$), Q is air flow rate ($m^3.h^{-1}$) and V_b is bed volume (m^3).

3 RESULTS AND DISCUSSION

3.1 Long-term biofilter operation

The EBRT was 3.9 min during the start-up period. The increase of the inlet concentration during the first three days caused a drop of removal efficiency of styrene (Figure 2). When the inlet concentration was kept stable at 650 $mg.m^{-3}$, the RE increased from 50 % to 98 % in 5 days.

Neither the slow increasing of inlet concentration between days 10 and 22 nor the step change of the inlet concentration from 700 to 1300 $mg.m^{-3}$ had no negative effect on RE which remained above 97 %. From this, it can be concluded that the start up-period took 15 days. The similar duration of start-up period was reported by Kraakman *et al.* (1997) (14 days), Juneson *et al.* (2001) and Arnold *et al.* (1997) (12 days) in biofilters. A much longer start up period was observed by Cox *et al.* (1993) for styrene removing biofilter inoculated with fungus *Exophiala jeanselmei* (4 – 5 weeks).

Values of the inlet concentration from 50 to 1520 $mg.m^{-3}$ and the EBRT from 0.4 to 3.9 min were used to test the biofilter stability under different loading manners (Figure 2a). The organic load ranged from 5.6 $g.m^{-3}.h^{-1}$ to 23.2 $g.m^{-3}.h^{-1}$. The removal efficiency did not drop below 95 % during the entire biofilter operation with the exception of the start-up phase (cf. Figure 2b, days 1-10) and the step change of the inlet concentration (day 104, Figure 4). It can be concluded that the degradation ability was very high and stable during a long-term operation, despite the very different loading conditions have been used.

3.2 Responses of non-use periods

Figure 3 shows the dynamic behavior of the re-starting period after varying periods of non-use. The data are not included in long-term performance plots. 8, 69 and 95 h of interruptions were tested. The inlet concentrations before these periods were 50 $mg.m^{-3}$, the outlet concentrations were 0 $mg.m^{-3}$ (RE = 100 %) and EBRT was 0.39 min. It is evident that the non-use periods had minimal effect on the biofilter

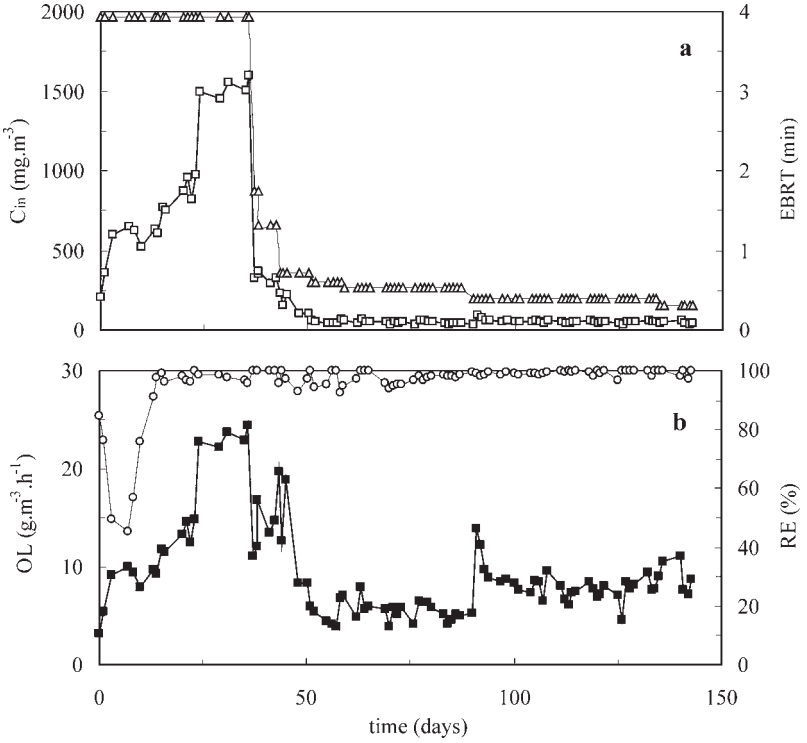

Figure 2. Overall performance characteristics. □ – C_{in}; Δ – EBRT; ■ – OL; ○ - RE

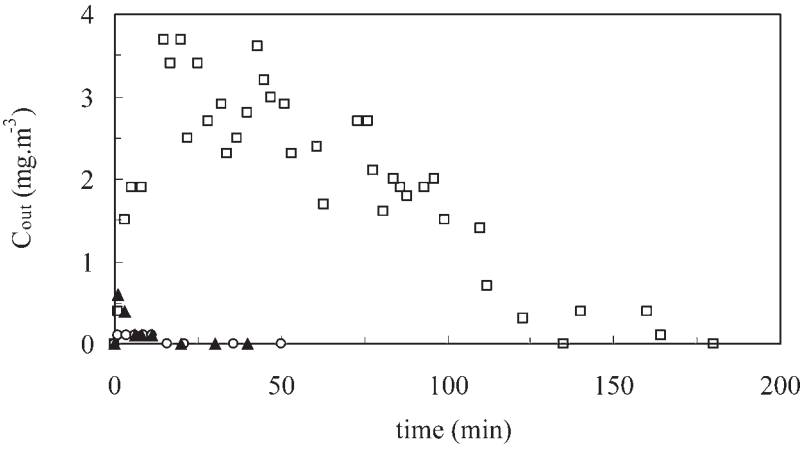

Figure 3. The dynamic behaviour of the re-starting periods after 8 hours (○) - day 127, 69 hours (▲) - day 132, 95 hours (□) - day 140 of non-use periods.

performance. The maximum outlet concentration after the re-starting of the loading rate of 50 mg.m^{-3} was 4 mg.m^{-3}, when a 95 h idle period was used. After shorter idle periods, the outlet styrene concentrations did not exceed 0.6 mg.m^{-3}.

The recovery of RE (to 100%) took several minutes only in cases of the non-use periods lasting 8 and 69 h, while 2.8 h was necessary in a case of the longest non-use period. Martin and Loehr (1996) for biofilter treating benzene reported two times longer response (4.2 h) to non use periods (40 and 90 h). When the non-use period lasted several days or several weeks, the biofilter recovery ranged from several days to even several weeks (Martin and Loehr, 1996; Bastos *et al.*, 2003).

3.2 Dynamic responses to step changes of inlet concentration

A dynamic response on a double step-change of the inlet concentration from 50 to 200 mg.m^{-3} was carried out on day 104 of operation. The step changes and the intermission lasted the same time (40 min). The EBRT value was 0.39 min.

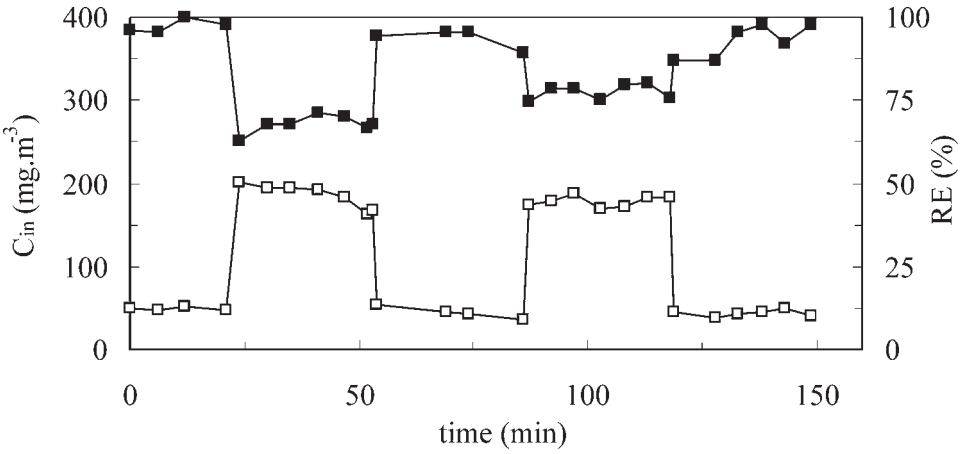

Figure 4. Dynamic response on a double step-change of inlet concentration. □ – RE; ■ – OL

The first step-change of the styrene inlet concentration resulted in a drop of the RE (from 98 % to 62 %). As it can be seen from Figure 4, a mild recovery of removal efficiency occurred during that step-change (from 62 % to 68 %). The second step-change of the inlet concentration caused a smaller decrease of the RE than that of the first one (only to 77 %). However, the recovery of the biofilter was longer than in case of the first change. The original RE was achieved in 20 min before decreasing the inlet concentration to 50 mg.m^{-3} again.

4 CONCLUSIONS

- The biofilter showed a stable degradation ability under very different loading patterns.
- The tested non-use periods had almost no effect on the biofilter performance.
- Step changes of the inlet concentration caused drop of the RE (to 62 %). Nevertheless, they had no effect on the long-term degradation rate of styrene.

5 ACKNOWLEDGEMENT

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