Treatment of styrene- laden waste gas stream using compost-based biofilter

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ABSTRACT

Biofiltration of air containing styrene vapor was investigated using a three-stage bench scale biofilter. The biofilter was packed with yard waste compost using hard plastics as a bulking agent in a 75:25 v/v mix of plastics: compost. The feed concentration was made by bubbling air through a styrene stock solution. The system was inoculated with thickened activated sludge and the effects of loading rate, inlet concentration and empty bed contact time variations on the performance and operation of biofilter were studied. During the start up period of about 65 days, microbial assimilation to styrene was achieved with inlet concentration of 270 mgm^{-3} and bed contact time of 6 min. Under steady state conditions experimental results showed overall removal efficiency of 92±2% at loading rates 31±2 $gm^{-3}h^{-1}$ and empty bed residence time (EBRT) of 120 s. No reduction in performance was observed at organic loading rate (OLR) values of up to 60±3 $gm^{-3}h^{-1}$ and elimination capacity remained at 49±2 $gm^{-3}h^{-1}$. Evaluation of the concentration profile along the bed height indicated maximum elimination capacity occurring in the first section of biofilter with styrene removal efficiency of around 50%. Elimination capacities showed a decreasing trend once EBRT was reduced to 30 s. There was no indication of excessive biomass growth and consequent increase in pressure drop during the 200 days of study.

INTRODUCTION

Styrene is produced in larger quantities in the chemical industry and its monomer constitutes the building block for the production of polystyrene, styrene copolymers, polyester resins and rubber. It is also used in the production of glass fiber reinforced plastics like boats, storage tanks, pipes, shower units and car parts. Besides the known industrial releases from the production and processing units, styrene is also generated in smaller quantities from other sources such as natural microbial and fungal metabolism, cigarette smoke, automobile exhaust and the pyrolysis and cracking of petroleum and its derivatives.[1-4]

Styrene has been listed among the 189 hazardous and toxic atmospheric contaminants under CAAA (1990) because of its adverse effect on human health.[3] Acute exposure to styrene in humans results in mucous membrane and eye irritations as well as gastrointestinal disorders. Chronic exposure to styrene in humans results in

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a variety of discomforts such as headache, fatigue, weakness, and depression, central nervous system dysfunction, hearing loss, and peripheral neuropathy.[5]

Among the various emerging air pollution control technologies, biofiltration is an effective option for treatment of such volatile organic compounds (VOCs) emissions. It has been widely and efficiently applied for the treatment of air streams contaminated by VOCs at low concentrations. Various natural residues like compost, peat, wood bark, and synthetic materials such as certain ceramics, glass, and polystyrene spheres are most frequently used as the media for biofilm support.[3,7]

Biofiltration of air contaminated with styrene has previously been investigated by a number of researches, both at the bench and pilot scales. Results reported by Paca (2001) indicated an elimination capacity of 140 $gm^{-3}h^{-1}$ at removal efficiencies greater than 90% was possible in a bench scale Perlite biofilter. Heitz (2000) studied the effect of nutrient concentration and observed better microbial preference for ammonia as compared to nitrate. Styrene EC values of up to 141 $gm^{-3}h^{-1}$ using ammonia and 50 $gm^{-3}h^{-1}$ using nitrate was reported in this study. Zilli[7] has reported maximum elimination capacity of 63 $gm^{-3}h^{-1}$ to biofiltration of styrene filled with packing material consisting of a mixture of peat and glass beads. Arnold (1997) has developed a biofiltration process for styrene containing off-gases using peat as filter material and mean elimination capacity has been 12 $gm^{-3}h^{-1}$ with maximum value reported to be 30 $gm^{-3}h^{-1}$.

MATERIALS AND METHODS

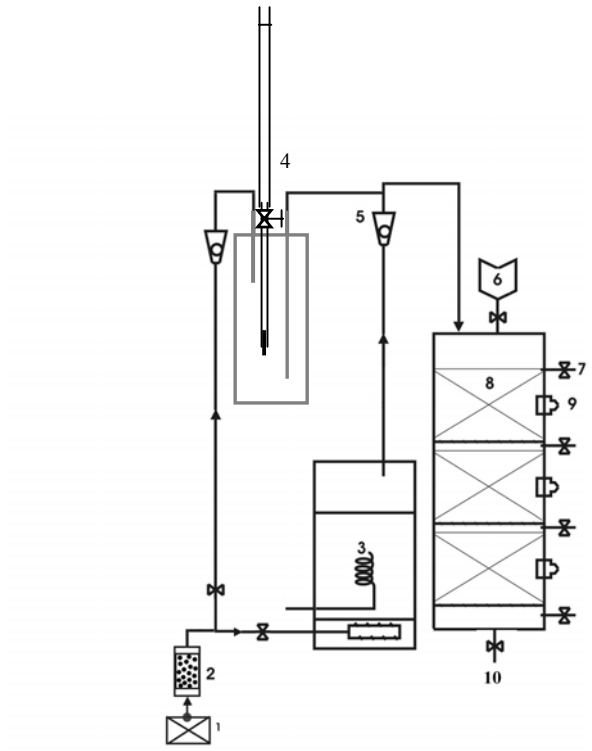
A three-stage biofilter constructed from galvanized iron were used in this study (Figure 1). The column had an inner diameter of 8 cm and the effective height of bed media was 120 cm. Perforated steel plate plenums (pore diameter = 2 mm) placed between sections acted as a support for the packing material as well as for flow redistribution. A 7-cm space in between the sections allowed for representative gas sampling. Provision of sampling ports at top, midpoint and at the end of each section allowed bed media access.

The synthetic waste air stream was prepared by sending compressed air through a granular activated carbon canister to adsorb residual oil and remove particles. The air stream was then sparged through a 15-l water container equipped with heated element for water temperature control and humidification. Pollutant vapor was prepared by introducing low flow air stream into a container receiving drop-wise styrene feed from a burette. After humidification, the main air stream was mixed with the stream containing pollutant vapor to generate feed air with the needed concentration. Changing water temperature in the humidifier controlled variation of humidity in the influent gas stream and biofilter material. Temperature control of the bed material was achieved by using a heated tape wrapped around the exterior of reactor wall. During the study, bed temperature and humidity were maintained at 30±1 °C and 60-65%, respectively.

Bed Media was prepared by mixing Yard waste compost (Tehran Compost Company) and shredded high-density plastics (1.5 cm) as bulking agent to produce a 25:75 w/w ratio of compost-bulk agent. In preparing the packing medium, thickened municipal activated sludge (Tehran wastewater authority) was added to this mixture to enhance microbial population and reduce the length of acclimation period. Nutrient and buffering solution used had the following composition (units in g/L): KH_2PO_4, 0.694; K_2HPO_4, 0.854; $(NH_4)_2SO_4$, 1.234; $MgSO_4.H_2O$, 0.46; $CaCl_2.2H_2O$, 0.176; $FeSO_4.7H_2O$, 0.001 and 5 ml trace element solution (H_3BO_3, 60 mg/l; $CoCl_2.6H_2O$,

40; $ZnSO_4.7H_2O$, 20; $MnCl_2.4H_2O$, 6; $NaMoO_4.2H_2O$, 6; $NiCl_2.6H_2O$, 4; $CuCl_2.2H_2O$, 2) with an overall pH of 6.9 ± 2 and C/N ratio of around 30 [5].

Figure 1 – Schematics of biofilter system (1-compressor, 2-carbon filter, 3-humidifier, 4- pollutant vessel, 5-rotameter, 6-nutrient, 7-gas sampling port, 8-biofilter bed, 9-bed sampling port, 10-leachate)



RESULTS AND DISCUSSION

Biofiltration of styrene vapor was investigated for a period of 10 months. During the startup period, the system was packed with shredded hard plastic and thickened activated sludge and it was operated with an EBRT of 360 s, stream velocity of 56.25 mh^{-1}, and feed styrene mean concentration was 68±11 ppm. Removal efficiency of the system reached up to 80% after about 6 days and with time it increased to around 90% within 45 days (Figure 2). The fluctuations in the inlet concentration were inevitable considering the experimental setup of styrene volatilization through air bubbling into a stock solution. The observed acclimation period in this study was compatible with others reported in the literature for styrene [8-10].

Analysis of styrene concentration profile along the biofilter column showed low performance for the first section till about 40 days from the startup. As shown in Figure 3, a longer period was needed for section 1 to reach its optimal performance when compared to section 2. For example on day 13, there was 20% removal in section 1 while more than 60% was removed in section 2. The difference in performance was believed to be attributed to low moisture content since other conditions were the same. Determination of water content confirmed the hypothesis as

it was observed that a decrease in moisture down to less than 35% was encountered. This was so due to low water retention capability of plastic media used as bulking agent. Previous studies have confirmed that if the water content goes to less than 50%, removal efficiency can suffer by up to 50% [11]. To improve performance, compost was added to the system resulting in increased removal efficiencies of up to 100%.

Figure 2- Performance of biofilter at the start-up time

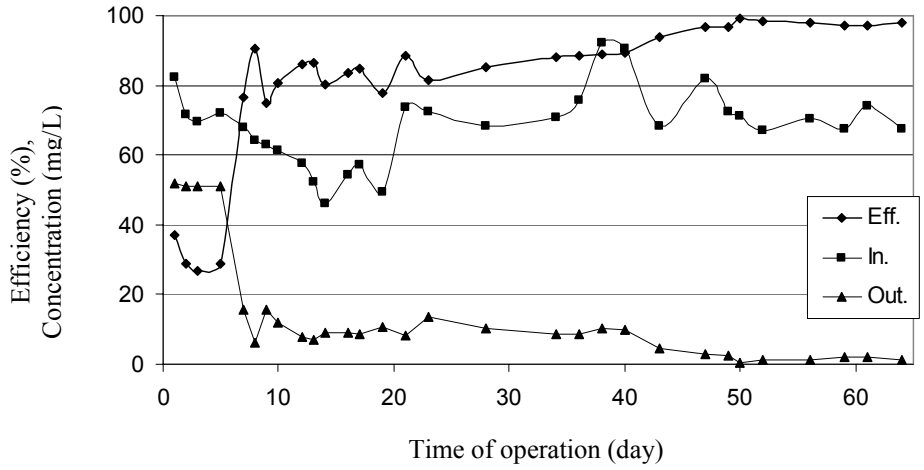


Figure 3- Styrene concentration profile along the bed height at the start-up

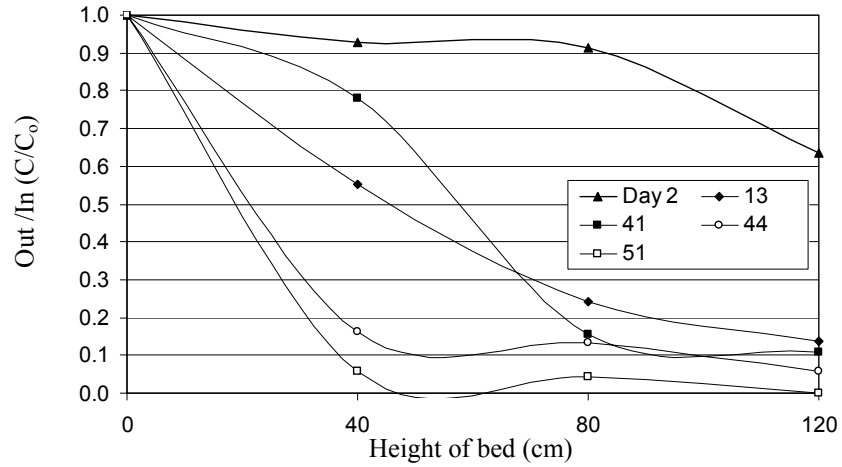


Figure 4 shows the concentration profile along column of biofilter at different organic loading rates (OLRs). First section showed better performances for loading rates 60 and 80 $gm^{-3}h^{-1}$ and there was no difference in elimination capacity for inlet concentrations 250 and 500 ppm. However, further increase showed an adverse impact with possible indication of the inability of maintain suitable elimination

capacity. As shown in Figure 5, maximum elimination capacity is about 84 $gm^{-3}h^{-1}$ for OLR close to 120 $gm^{-3}h^{-1}$. When styrene loading rate was less than 60 $gm^{-3}h^{-1}$, removal efficiency was more than 88% and for OLR less than 30 $gm^{-3}h^{-1}$ at EBRT of 120 s it was about 92%.

Performance of the system was studied as a function of hydraulic residence time in the range of 30 to 120 s and the results are shown in Figure 6. The data shown represent the situation after the initial adaptation period of a week after any change. At first system was operated with EBRT of 120 s and inlet concentration of around 1000 ppm, with removal efficiencies of 84 ± 3% up to day 43. Addition of nutrient to the system resulted in a sharp increase in removal efficiency to the maximum value of around. Flow rate was increased to 6 $lmin^{-1}$ with no rise in styrene concentration so mass loading changed proportionally and reached 60 $gm^{-3}h^{-1}$.

Figure 4-Concentration profile along the bed height at different OLRs and EBRT= 60 s

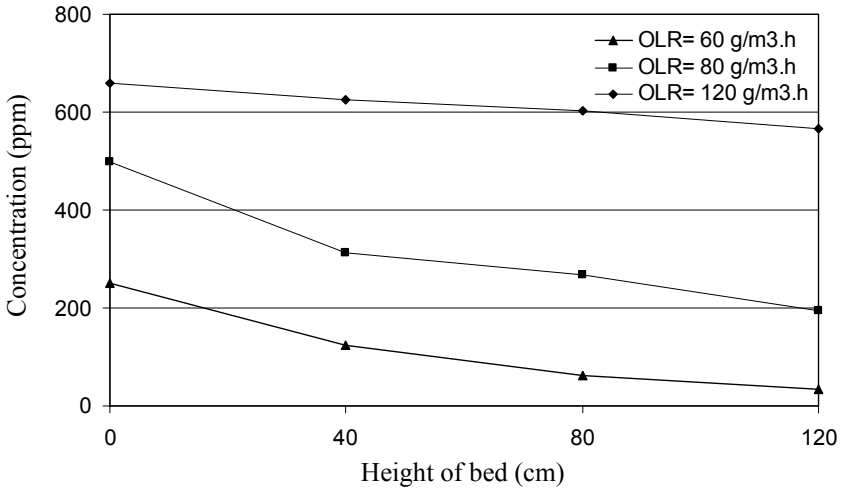
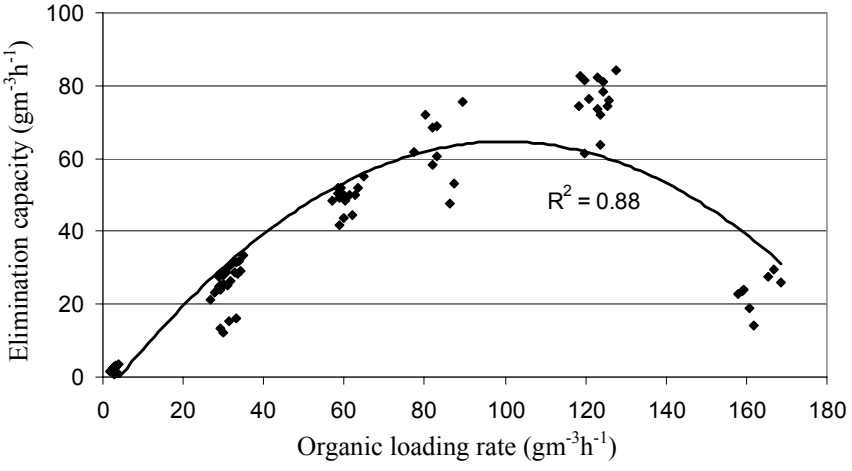


Figure 5- Overall performance of biofilter in removing styrene as at different OLRs



At the beginning of each step change in feed concentration, there was a larger than normal fluctuation in removal efficiency with gradual recovery and increasing trend with time. Step changes in concentrations were from 1400 to 2000 to 2700 ppm at days 106, 136 and 170, respectively. Removal efficiency was decreased to about 55% for both the first and second changes, but the time to recovery was very short for the first step change and removal efficiency reached the original level prior to increase in the loading rate. However for the third increase in styrene concentration, removal efficiency was decreased by about 15% and never recovered. At low EBRT of 30 s at inlet concentration of about 1000 ppm, the removal efficiency was less than 40%.

Figure 6- Overall performance of biofilter at different EBRT

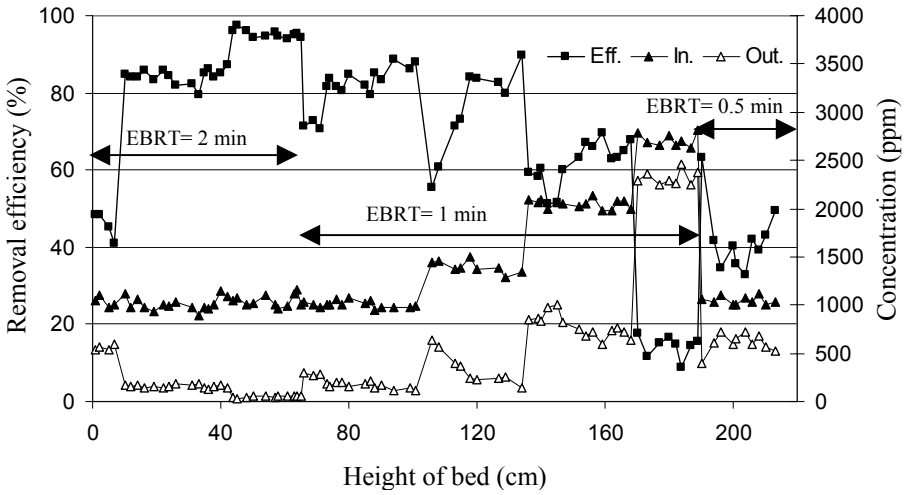


Figure 7 shows performance of individual sections of biofilter at removing styrene. The first section in all EBRTs has the best performance and for EBRT of 120 and 60 s removal efficiencies are about 55 and 50%, respectively.

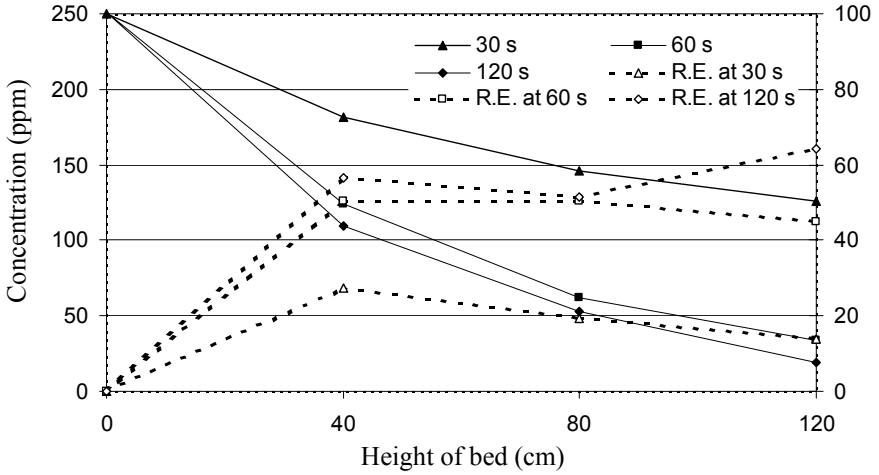
CONCLUSIONS

- Acclimation period for biofiltration of styrene was more than other VOCs such as BTEX at about 45 days.
- Compost improved performance of biofilter because of high water retention capacity
- Maximum styrene elimination capacity was about 84 $gm^{-3}h^{-1}$ for OLR values close to 120 $gm^{-3}h^{-1}$.
- The first section at all EBRTs has the best performance and for EBRT of 120 and 60 s removal efficiencies were around 55 and 50%, respectively.

KEYWORDS

Biofilter, Styrene, Compost, waste gas, biological treatment, industrial air pollution

Figure 7- Concentration profile along the biofilter column at different EBRT



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