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2C4) Removal of Benzene Vapors in a Compost Biofilter

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1. INTRODUCTION

Benzene is an important chemical feedstock, which is used as a raw material for the synthesis of fine chemicals and many dyestuffs. Due to improper practices and treatment, substantial amount of vapors containing benzene are being emitted to the ambient atmosphere from process industries. It is reported to have significant effect on human health and natural environment [1]. This has led to increased attention from the regulatory authorities and continuous development of the existing control technologies is in progress. Biodegradation is a promising alternative for the mineralization of volatile organic compounds (VOCs). The most widely used biological processes for waste gas treatment are bioscrubbing, trickling biofilters and biofilter. The simplicity in the operation of biofilters has resulted in its emergence as a more practical treatment option. Biofilters have also proven to be effective in treating large volumes of VOCs at relatively low concentrations [2]. A complex phenomenological step consisting of adsorption, absorption, diffusion and biodegradation takes place in a biofilter where the pollutant is converted to non-toxic end products [3]. Furthermore, the removal and oxidation rates of these hazardous contaminants depend principally on the biodegradability, reactivity and largely on the solubility of the pollutant in the liquid layer of the biofilm. Biofiltration studies have been tested with a wide variety of pollutants having different degradation rates. Removal of ethanol vapors was studied in a compost biofilter that gave a maximum EC of 195 g/m^3.hr, and results from transient behavior studies have demonstrated a stable biomass activity [4]. Lab scale studies for the removal of toluene vapors in a compost biofilter has shown a maximum elimination capacity (EC) of 128.1 g/m^3.hr and when tested with an actual industrial gas mixture containing toluene and benzene showed high removal efficiencies [5]. The removal characteristics of mixtures of NH_3 and H_2S in a biofilter packed with a novel biomedia encapsulated with an organic polymer showed stable removal efficiencies greater than 99% for 60 days [6]. These experimental studies have proved biofiltration as an efficient waste gas treatment process and a reliable technology for the control of VOCs. This paper present the performance of a compost based mixed culture biofilter treating benzene vapors at high concentrations.

2. MATERIALS AND METHODS

2.1 Microbial seed

A mixed microbial culture obtained from a municipal sewage treatment plant was acclimatized with benzene as the carbon source in a mineral salt medium. This culture was used to inoculate the biofilter.

2.2 Biofilter

The biofilter was constructed from a perspex tube (5 cm diameter and 70 cms height). The packing in the biofilter consisted of a mixture of sieved compost (3-6 mm) and ceramic beads (4-6 mm). A perforated plate at the bottom provided the support for the packing while the addition of ceramic beads provided the structural strength for the packed bed. Gas sampling ports sealed with rubber septa were provided at equal intervals along the biofilter height.

2.3 Experimental

A schematic of the experimental setup is given in Figure 1. Humidified benzene vapors at constant flow and concentration, controlled through valves were passed through the bed in an up flow mode. The bed was initially inoculated with the benzene acclimatized mixed culture. The bed moisture was maintained by periodic addition of fresh mineral salt medium from the top. Experiments were carried out by varying the flow rates of the benzene vapors and humidified air independently to get different initial concentrations and residence times in the biofilter. Gas samples were collected from different ports and analyzed for residual benzene concentration.

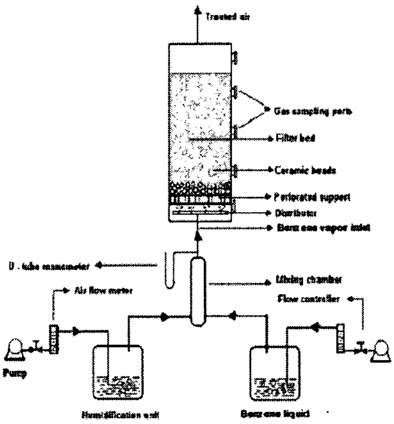

Fig. 1.Schematic of the experimental biofilter setup.

2.4 Analytical methods

Benzene concentration in gas samples were measured by gas chromatography (Model 5765, Nucon gas chromatograph, Nucon Eng. India) using a stainless steel column and a flame ionization detector. Nitrogen was employed as the carrier gas at a flow rate of 20 ml/min. The temperatures at the GC injection, oven and detection ports were 150, 120 and 250C respectively.

3. RESULTS AND DISCUSSION

The performance of the biofilter was evaluated in terms of two parameters, the removal efficiency (RE, %) and the elimination capacity of the filter bed (EC, $g/m^3.hr$).

The biofilter was initially acclimatized by operating the biofilter at low concentrations (0.04-0.07 g/m^3) and low gas flow rates of 0.06 m^3/hr for 45 days to obtain sufficient biomass concentration in the filter bed. The degree of acclimatization primarily depends on the adaptive capability of the microorganisms present in the compost or peat, substrate concentrations, nutrient concentration and its availability and other necessary environmental conditions. However, the efficient functioning of any biofilter unit strongly depends on the inlet pollutant load [7]. The combined effect of benzene inlet concentration and gas flow rate was investigated in three phases (I, II and III) as described in Table 1 and the results are shown in Figure 2. It could be observed that the biofilter operated at high efficiencies (60-90%) till an initial concentration of about 1.6 g/m^3. The outlet concentration remained fairly uniform even when the inlet concentrations were fluctuating. At higher concentrations, the removal efficiency decreased rapidly to 40%. Similarly the removal efficiency decreased with increase in flow rate. Figure 3 shows the effect of inlet concentration on the removal efficiency throughout the experimental period. Higher concentrations show a significant reduction in removal efficiency, which may be due to insufficient biomass in the filter bed to utilize the substrate or due to substrate inhibition at high concentrations. Moreover, the removal profiles of benzene vapor at higher concentrations indicate that biomass concentration in the filter bed may be the limiting factor.

Table 1. Experimental scheme for continuous benzene degradation experiments

Phases of biofilter operation	EBRT, mins	Average inlet concentrations, g/m^3	Operating time, days
Acclimatization	1	0.04 - 0.07	45
Phase I	2.45	0.2 - 0.8	50
Phase II	1.63	0.4 - 1.0	39
Phase III	0.81	0.8 - 1.7	28

- EBRT Empty Bed Residence Time

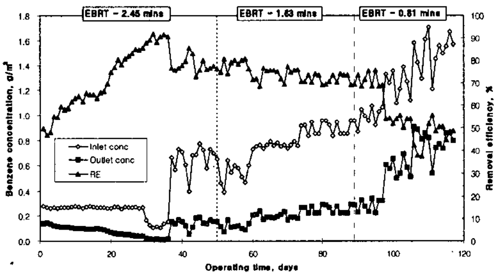

Fig. 2. Variation in removal efficiency with change in gas flow rate and inlet benzene concentrations.

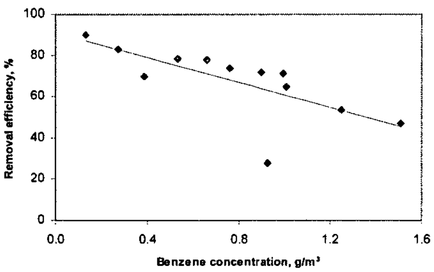

Fig. 3. Influence of the inlet benzene concentration on the removal efficiency of the biofilter (points represented here are the average for each experimental run).

The elimination capacity, which reflects the capacity of the biofilter to remove the pollutants, is plotted as a function of the inlet benzene load in Figure 4. A near linear relation between the two variables was observed till an inlet load of 40 g/m^3.hr, which corresponded to phase I and phase II operations. However for higher initial concentration and higher flow rate used in phase III, the elimination capacity of the filter bed increased initially and soon became constant at higher inlet loads. At inlet load beyond 60 g/m^3.hr and up to 130 g/m^3.hr, the EC remained nearly constant between 30-65 g/m^3.hr. The biofilter was able to achieve a maximum removal capacity of 64.8 g/m^3.hr at an inlet load of 124.8 g/m^3.h. This trend also substantiates the fact that biomass concentrations may be the limiting factor in benzene removal at higher concentrations. The results from this study were comparable to some of the studies reported in literature using compost biofilters. The dynamics of benzene removal was understood by plotting the normalized benzene concentration profiles as a function of the biofilter height (Figure 5). The results indicate that the removal is more efficient in the lower part of the biofilter than in the upper part of the filter. Nearly 40% of benzene was removed in the first 20 cms of the bed height, while the rest of the 30 cms removed only an additional 20-25%. This may be due to a higher concentration of microbial population and higher moisture content in the lower section of the filter bed.

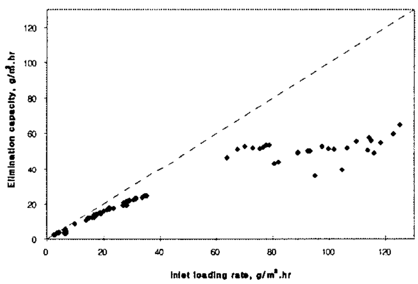

Fig. 4. Influence of inlet benzene load on the elimination capacity of the biofilter.

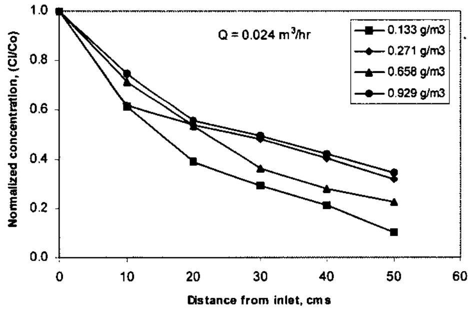

Fig. 5. Normalized benzene concentration profiles as a function of the biofilter height.

4. CONCLUSION

The performance of the biofilter was assessed by studying the effects of flow rate and inlet benzene concentration on the removal efficiency and elimination capacities of the filter bed. The biofilter attained a maximum elimination capacity of 64.8 $g/m^3.hr$ at an inlet load of 124.8 $g/m^3.hr$. The removal efficiencies were greater than 80% when the gas flow rate was 0.024 m^3/hr and inlet concentration was less than 0.5 g/m^3.

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