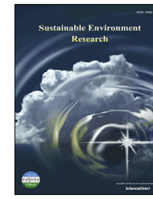
Sustainable Environment Research xxx (2017) 1–7

Contents lists available at ScienceDirect

Sustainable Environment Research

journal homepage: www.journals.elsevier.com/sustainable-environment-research/



Original Research Article

Microbial biofilter for toluene removal: Performance evaluation, transient operation and theoretical prediction of elimination capacity

Srikumar Malakar [a,*], Papita Das Saha [b], Divya Baskaran [c], Ravi Rajamanickam [c]

[a] Environment, Water & Safety Division, Engineers India Limited, Gurgaon 122001, India
[b] Department of Chemical Engineering, Jadavpur University, Kolkata 700032, India
[c] Department of Chemical Engineering, Annamalai University, Chidambaram 608002, India

ARTICLE INFO

Article history:
Received 1 June 2017
Received in revised form
31 October 2017
Accepted 7 December 2017
Available online xxx

Keywords:
Biofilter
Performance
Transient condition
Ottengraf model
Biofilm thickness

ABSTRACT

Toluene contributes a major part amongst the hazardous volatile organic compounds (VOCs). In this present work, toluene removal in a novel lab scale biofilter packed with ceramic beads and compost has been studied after 20 d of acclimatization. For different initial toluene concentrations (0.2–3.7 g m^{-3}), the elimination capacity (EC) and removal efficiency (RE) are studied. A maximum EC of 96 g m^{-3} h^{-1} was found at the toluene inlet loading rate of 98.8 g m^{-3} h^{-1} with high RE of 97% during its 22 d continuous operation. The removal of toluene biofilter was better at the entry section of the contaminated air. The study also showed stability of biofilter during transient operation in treating toluene. The experimental EC values are compared with theoretical EC values from mathematical model. The theoretical average biofilm thickness was found to be 0.47 mm. The Ottengraf mathematical model was able to predict the theoretical EC at different regime of biofilter operations.

1. Introduction

Various wastewater streams generated in petroleum refinery process units, offsite storage area and utility areas are routed to Effluent Treatment Plant (ETP). In this process ETP receives different volatile organic compounds (VOCs) (namely benzene, ethyl benzene, toluene, xylene, methyl tertiary-butyl ether, naphthalene, phenol, styrene etc.) dissolved in wastewater and thereafter these VOCs are emitted to atmosphere due to their low boiling point and high vapor pressure at room conditions [1]. The released VOCs may exhibit the carcinogenic and mutagenic effects on human and vegetation in the proximity of emission sources [2]. This adverse issue is attracting increasing interest from both industry and government authorities worldwide which in turn prompted the oil and gas exploration and production industry to focus on treatment technologies to minimize these emissions. The sources of VOC emissions from the petroleum industry include combustion, process operations and fugitive emissions. Also, VOCs that are leaked from the production/process and storage equipments/pipelines contribute to the overall pollution [3,4]. In this regard, toluene is a major component of the VOCs found in petroleum refining. It is used extensively in solvents, fuels and as raw material for other chemical products.

Many literature have evidenced that toluene is widely seen as an atmospheric contaminant. It causes serious damage to the liver, kidney and nervous system even at lower concentrations [5–7]. Due to these health issues, toluene with higher vapor pressure (30 mm Hg at 25 °C) [8] and lower water solubility (515 g m^{-3} at 25 °C) [9] needs to be removed effectively from contaminated gas or liquid stream [10,11]. Treatment of VOCs in vent gases is required to meet the refinery and USEPA emission norms and other statutory guidelines. Over the years, biofiltration has been ascertained as a cost effective and applicable option to treat toxic VOCs emitted from operations that are handling large off-gas volumes at lower concentrations [12–14]. This process can efficiently remove contaminant concentration as high as 5000 ppm provided proper designing & operation are followed [15]. Biofilter also needs little nutrient addition for microbial growth with no hazardous secondary pollutants produced [16,17]. Biofiltration is a process that involves a combination of different processes including adsorption, biodegradation and desorption of gas phase toxic pollutants [18].

* Corresponding author.
E-mail address: srik09@gmail.com (S. Malakar).
Peer review under responsibility of Chinese Institute of Environmental Engineering.

https://doi.org/10.1016/j.serj.2017.12.001

However, a biofilter with packing material is typically inoculated with microorganisms such as mixed bacteria and fungi strains [19–21]. The packing material is always selected based on the surface and pore structure and their characteristics are important for improving efficiency. The packing material may be compost, peat or peat/perlite mixture, wood chips, and other organic/inorganic commercial media materials [22–24]. The biofilter performance is influenced by a number of factors such as inlet load, air velocity, humidity, pressure drop, pore size distribution and pH of the filter bed [25–27].

Many researchers have reported high removal efficiencies in their lab scale biofilters for the removal of toluene vapors with compost packing media [28,29]. Rene et al. [30] studied the compost biofilter for a long-term removal up to 8 months of gas phase toluene, wherein a maximum elimination capacity (EC) of 65 g m^{-3} h^{-1} is obtained at inlet loading of 125 g m^{-3} h^{-1}. Due to the prominence of toluene as a major VOC, many researchers have used toluene as the main carbon substrate in their biofiltration experiments [31–33]. Baskaran et al. [34] studied the influence of substrate concentration, nutrients and temperature on the biodegradation of toluene in a compost biofilter reactor. In this study, a compost biofilter was designed to treat gas phase toluene under a long-time operation (~54 d); maximum EC of 93 g m^{-3} h^{-1} was observed at the inlet load of 114 g m^{-3} h^{-1} [35].

Laboratory scale experiments are useful in developing a realistic mathematical model that can be used for different conditions in explaining the contaminant degradation, biofilter performance and biofilm growth [36,37]. Ottengraf and Van Den Oever [38] refined the biofilter model for the biofiltration of VOCs. In this model, both diffusion and biodegradation of contaminants in the biofilm were considered [39]. The main objective of the present work is to evaluate the performance of biofilter having compost and ceramic beads as media bed while treating toluene vapors at varied concentrations. The EC and RE were studied and monitored under different operating scenarios. Further, the experimental values are compared with those predicted by the Ottengraf's model.

2. Materials and methods

2.1. Microbial seed

A mixed microbial culture was retrieved from a previously studied toluene biofilter bed [35]. Cow dung compost intrinsically contains nutrients like N, P and K which are crucial for the microbial sustainability. Microorganisms in the compost were first acclimatized with toluene as a carbon source along-with periodically addition of well-defined MSM (mineral salt medium) for accelerating the adaptation period in subsequent operation. The acclimatization was done at the ambient condition and the pH of the medium was kept at 6.9. Packing bed was prepared by mixing the compost and ceramic beads (1.5:1 ratio). An ideal media bed should last long and offer lower pressure drop across the bed. For supplying continuous nutrient to filter bed, MSM was used with the following components in g L^{-1} of distilled water: Na_2HPO_4: 5; K_2HPO_4: 4; KH_2PO_4: 4; $(NH_4)_2PO_4$: 1; $MgSO_4 \cdot 7H_2O$: 0.25; $CaSO_4$: 0.25; and $FeSO_4 \cdot H_2O$: 0.08. The total N:P ratio in compost and MSM were 2.5:0.5 and 0.07:1 respectively.

2.2. Experimental reactor set up

The biofilter column was constructed with 40 cm long and 60 mm diameter of polyacrylic tube. Fig. 1 shows the flow diagram of experimental biofilter setup. A perforated plate placed at the bottom accommodated the support for packing. There are 3 gas sampling ports sealed with rubber cork at equal intervals along the filter bed height of 30 cm. Liquid toluene was vaporized and humidified at constant air flow in a mixing chamber before entry to biofilter. Biofilter was operated in counter-current mode. Incoming

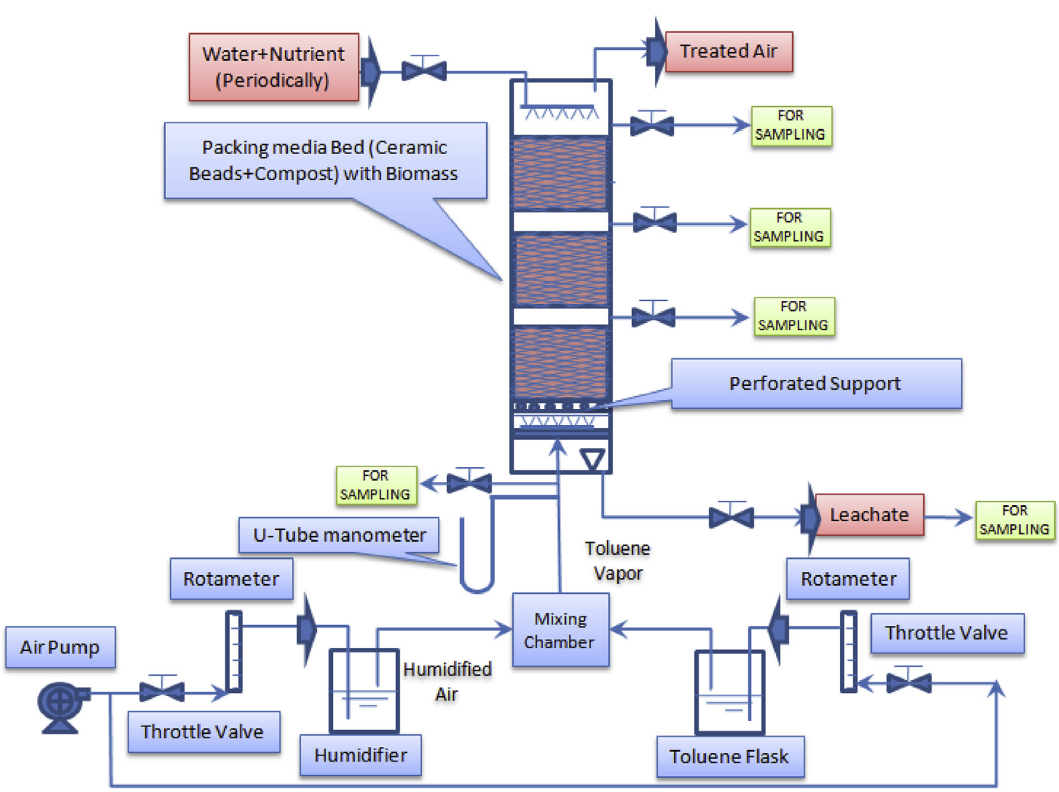


Fig. 1. Flow diagram-experimental biofilter setup [35].