Journal of Hazardous Materials 280 (2014) 235–243

Contents lists available at ScienceDirect

Journal of Hazardous Materials

journal homepage: www.elsevier.com/locate/jhazmat

Experimental investigation of the formaldehyde removal mechanisms in a dynamic botanical filtration system for indoor air purification

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HIGHLIGHTS

- The roles of different transport, storage and removal processes in a botanical air filter were investigated.
- Passing the air through the root bed with microbes was essential to obtain meaningful removal efficiency.
- Species of microbes also impacted the removal performance significantly.
- Moisture in the root bed also played an important role.
- The role of the plant was to introduce and maintain a favorable microbe community.

ARTICLE INFO

Article history:
Received 12 May 2014
Received in revised form 26 July 2014
Accepted 29 July 2014
Available online 12 August 2014

Keywords:
Plant
Air cleaning
Microorganism
Formaldehyde

ABSTRACT

Botanical filtration has been proved to be effective for indoor gas pollutant removal. To understand the roles of different transport, storage and removal mechanism by a dynamic botanical air filter, a series of experimental investigations were designed and conducted in this paper. Golden Pothos (*Epipremnum aureum*) plants was selected for test, and its original soil or activated/pebbles root bed was used in different test cases. It was found that flowing air through the root bed with microbes dynamically was essential to obtain meaningful formaldehyde removal efficiency. For static potted plant as normally place in rooms, the clean air delivery rate (CADR), which is often used to quantify the air cleaning ability of portable air cleaners, was only ~5.1 m^3/h per m^2 bed, while when dynamically with air flow through the bed, the CADR increased to ~233 m^3/h per m^2 bed. The calculated CADR due to microbial activity is ~108 m^3/h per m^2 bed. Moisture in the root bed also played an important role, both for maintaining a favorable living condition for microbes and for absorbing water-soluble compounds such as formaldehyde. The role of the plant was to introduce and maintain a favorable microbe community which effectively degraded the volatile organic compounds adsorbed or absorbed by the root bed. The presence of the plant increased the removal efficiency by a factor of two based on the results from the bench-scale root bed experiments.

1. Introduction

Indoor air quality (IAQ) is a very important building environment issue since it can significantly affect people's health, comfort, and also generate influence on productivity. Common indoor plants may provide a valuable means in fighting against rising level of indoor air pollution. Studies have shown that indoor potted-plants can significantly reduce many types of air-borne pollutants such as carbon monoxide, nitrogen dioxide, formaldehyde, benzene, arising from either outdoor or indoor sources [1–3]. Volatile organic compounds (VOCs) removal from indoor air by plants was first demonstrated in pilot screening studies by NASA, to test the uses of plants in space missions [4,5]. Following this work, detailed bench-top test chamber investigations on VOC removal by nine species of internationally used potted plants have been conducted, and found that indoor plants can eliminate high doses of VOC (e.g. 0.2, 1, 10, 100 ppm) in about 24 h [6–9].

Direct pollutant accumulation or degradation by plants is known to occur during phytoremediation of contaminated soils [10]. However, in botanical air filters, it appears that the role of plants is often suspected to support a microbial activity that is responsible for pollutant removal [11]. A recent study has suggested that bacteria

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http://dx.doi.org/10.1016/j.jhazmat.2014.07.059
0304-3894/

growing on plant leaves could also contribute to VOC biodegradation [12], but the ability of plant leaves to directly degrade pollutants during air treatment is still debated [13,14]. More generally, there is growing evidence of the complexity, and importance of interactions between plants and bacteria [15]. However, limited peer-reviewed data is available in literature, therefore there is an urgent need to improve the understanding of the fundamental mechanisms of VOC uptake or release by plants and their microbial hosts [16].

Our previous study has demonstrated that the dynamic botanical air filtration (DBAF) system performed well in removing both formaldehyde and toluene at low concentrations (less than 50 ppb), having consistently ~60% single pass efficiency for formaldehyde and ~20% for toluene over a 10-month test period [17–20], respectively. The test results represented the whole-filter performance in removing formaldehyde and toluene, but the intrinsic VOC removal mechanism is still not clear. More experimental research is needed to understand the underlying VOC removal mechanisms of DBAF. In particular, it is necessary to clarify the different roles played by the leaves, wet sorbent bed, and microbial communities. Therefore, this study presents the methods and results of a series of experimental studies that were designed to improve the understanding of the mechanisms of the DBAF system in removing volatile organic compounds. Factors affecting the removal performance was determined and quantified.

2. Materials and methods

To investigate the role of different mechanisms in formaldehyde removal by the botanical filtration system, the experiments were designed into three groups in current study:

Group A: formaldehyde removal by potted plant without air passing through the root bed (using test setup in Fig. 1),
Group B: formaldehyde removal by microbial community with air flow passing through (using test setup in Fig. 2),
Group C: formaldehyde removal by a dynamic botanical air filtration system (DBAF) (using test setup in Fig. 1).

All the tests were conducted in a conditioned lab space, where the temperature and relative humidity were maintained at 23 ± 0.6 °C and 50 ± 3%, respectively.

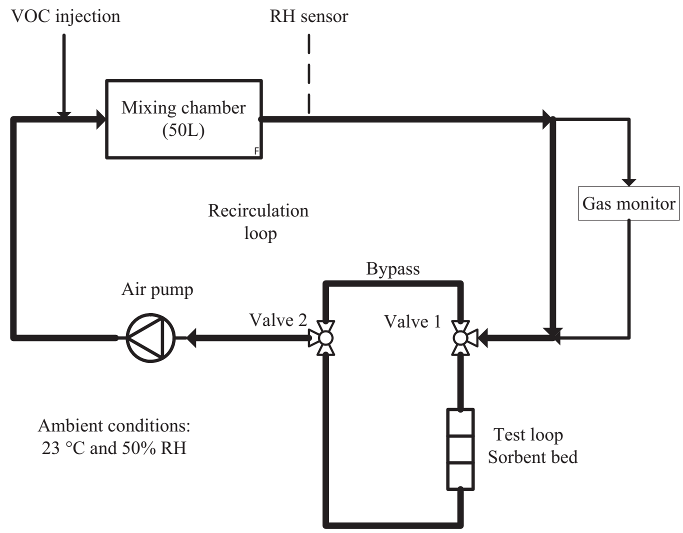

Fig. 2. Schematics of the recirculation test set-up for formaldehyde removal by "microbial bed".

2.1. Formaldehyde removal by static potted plant

The tests were conducted in a 5.1 m^3 stainless steel chamber with interior dimensions of 1.83 m length × 1.68 m width × 1.68 m height. The chamber was made to be air tight as much as possible (air leakage monitored for each test), and the temperature and RH can be controlled. In this group of tests, the potted Golden Pothos (*Epipremnum aureum*) plants (one or two), with its status just like how it is placed in homes and offices, were placed in the chamber in order to observe the static removal effect (without air passing through the root). The original soil in the pot was used. The schematic of this experimental setup is shown in Fig. 1. There was no ventilation for the chamber in this test, therefore the chamber served as a sealed space. A 6-in. propeller axial fan was placed in the middle of the chamber for better air-mixing purpose (equivalent air change rate of 20 ACH). Para-formaldehyde powder was heated by a hot plate (250 °C heating temperature set point) to serve as an instant formaldehyde source. Sulfur hexafluoride (SF_6) was used as a tracer gas. Formaldehyde was continuously monitored during the

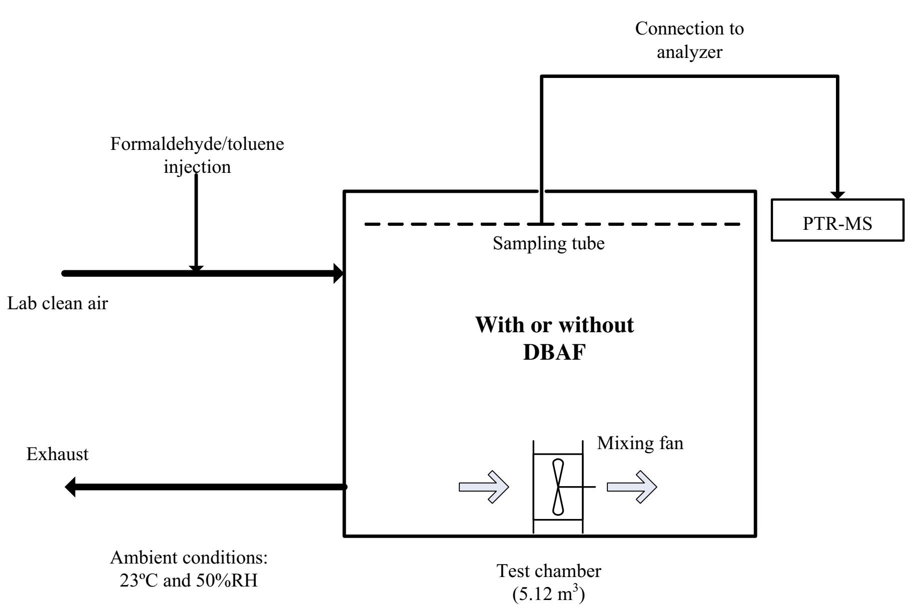

Fig. 1. Schematic of the mid-scale chamber system.