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Potential of Vermicompost Biofilter for the Removal of Formaldehyde

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Abstract. Biofiltration is a biological treatment used to remove pollutants from fluid media i.e. liquid or waste gas streams. A biofilter comprising an air pump, vermicompost volume of 6.38L and one golden pothos plant (*Epipremnum aureum* sp.) was assembled. This biofilter was subjected to inlet concentrations between 0.443 to 5.897g m^{-3} of formaldehyde for 8 hours per day, over a period of 16 days. Air samples were collected daily at 4-hour intervals from daily start-up. Mass of formaldehyde entering and exiting the biofilter was determined using US Environmental Protection Agency (USEPA) Method 323. Using this data, removal efficiency and elimination capacity was calculated. The investigated biofilter exhibited removal capacities above 94.8% throughout the experiment, with observed outlet concentration ranging between 0.003 to 0.079g m^{-3}. The highest elimination capacity observed during the experiment was 276.0±23.3g/m3/h. Vermicompost derived from spent mushroom compost and mixed organic kitchen waste was found to have removal capacities comparable to synthetic and composite packing media. The high elimination capacity exhibited suggests potential for the control of industrial emissions.

Keywords: biofilter, indoor air pollution, formaldehyde, vermicompost

1. Introduction

Formaldehyde is commonly used as an industrial fungicide, germicide, disinfectant and tissue preservative [1]. It can also be found in household products such as particle board, plywood, permanent press fabrics, glues and paper product coatings. Due to the presence and usage of these products in the indoor environment, indoor contamination from formaldehyde can reach concentrations ten times higher than outdoor air [2].

Workers in industries using formaldehyde as a major chemical component e.g. furniture industry face the risk of exposure to high concentrations of formaldehyde. For example, workers carrying out curing and coating processes at a furniture production factory were heavily exposed to formaldehyde at concentrations of 1.66-2.18ppm – exceeding the permissible exposure limit (PEL) standard of 0.30ppm [3]. Occupational exposure by inhalation is mainly from three types of sources: thermal or chemical decomposition of formaldehyde-based resins, formaldehyde emission from aqueous solutions or the production of formaldehyde resulting from the combustion of organic compounds (e.g. exhaust gases). Prolonged exposure to formaldehyde can result in diseases such as nasal mucosa, respiratory tract irritation and nasopharyngeal cancer [4]. Therefore, emission control technologies are necessary to reduce workers' vulnerability to adverse health effects.

Biofilters are able to meet modern demands for sustainable emission control technologies due to its low energy consumption, low chemical usage and cost setup. Biofiltration is a biological treatment technology, utilising principles of sorption and biodegradation by microbes as a means of removing toxicants from the atmosphere [5]. However, the technology has not been widely commercialised due to various operational

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issues [6]. Therefore, characterisation and modelling biofilter performance aspects are necessary in order to design bioreactors with robust operational control.

This study conducted was a pilot project to assess the potential of a biofilter comprising vermicompost and golden pothos, using ambient formaldehyde removal as indicator of biofilter performance.

2. Methodology

2.1. Biofilter set-up

To assemble the biofilter, 6.38×10^{-3} m^3 vermicompost was added to a polycarbonate cylindrical container measuring 25cm in diameter. The vermicompost used in the experiment was prepared using a mixture of spent mushroom compost and organic kitchen waste, according to a previously described method [7]. One *Epipremnum aureum* sp. (Golden pothos plant) was then placed in the centre of the vermicompost. The vermicompost was kept at moisture levels of 40% throughout the duration of the experiment. As shown in Figure 1, the biofilter consisted of an inlet port, one outlet sampling port and an opening at the top of the container, which was closed during sampling activities.

An artificial stream was supplied to simulate formaldehyde-contaminated air entering the biofilter. This was carried out by pumping ambient air at $0.3 m^3$ h^{-1} through a formaldehyde solution before entering the biofilter. The flow rate used was equivalent to an Empty Bed Residence Time (EBRT) of 76.6s. The formaldehyde inlet concentration (FIC) was increased in four(4) phases, by increasing the concentration of formaldehyde solution for each successive phase. Each phase lasted 4 days to obtain replicate values.

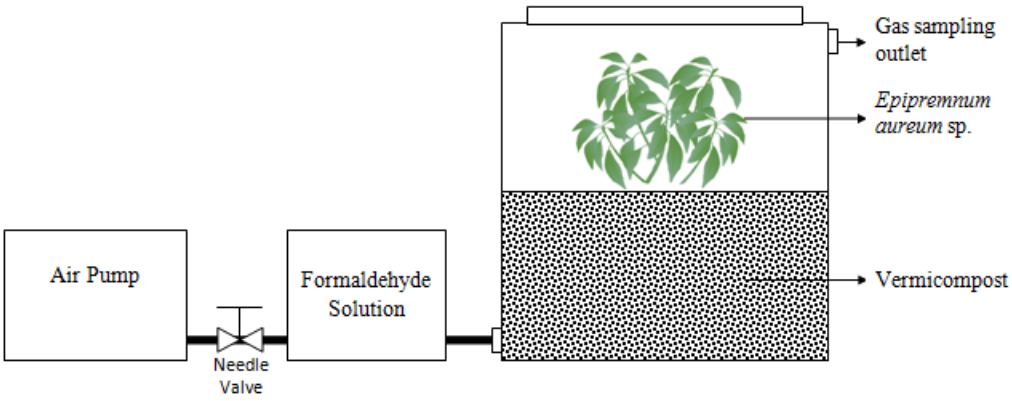

Fig. 1: Schematic diagram of experimental set-up

2.2. Sampling and analysis

Following USEPA Method 323 [8], air exiting the biofilter was bubbled into 100mL distilled water at a flow rate of 0.21L min^{-1} for 45 minutes to obtain sample solutions. Sampling was conducted at 4-hour intervals during the biofilter's daily operation. Samples were stored in a cool, dark place and analysed within 24 hours of sampling.

To determine the mass of formaldehyde dissolved in the sample solution, 2mL of each sample was reacted with 2mL acetyl acetone reagent. Formaldehyde in the sample undergoes the Hantzsch reaction with acetyl acetone to produce a yellow-coloured solution [9]. The sample's peak absorbance at wavelength range of 412-415nm was analysed using a UV-Vis spectrophotometer (Merck Pharo 300 Spectroquant). The concentration of formaldehyde in the air stream exiting the biofilter, henceforth referred to as formaldehyde outlet concentration (FOC), was then calculated using the data obtained.

2.3. Reagents

100mL acetyl acetone test reagent was prepared by dissolving 15.4g ammonium acetate, 0.3mL glacial acetic acid and 0.2mL acetyl acetone in sufficient distilled water. Ammonium acetate and acetic acid were purchased from Friendemann Schmidt whereas acetyl acetone was purchased from R&M Chemicals.

2.4. Data analysis

The following equations were used to calculate the biofilter's removal efficiency and elimination capacity:

Empty Bed Residence Time, $EBRT = \frac{V}{F}$ (unit: h)

Loading Rate, $L = \frac{C_i \times F}{V}$ (unit: g m^{-3} h^{-1})

Elimination Capacity, $EC = \frac{F(C_i - C_o)}{V}$ (unit: g m^{-3} h^{-1})

Removal Efficiency, $RE = \frac{C_i - C_0}{C_i} \times 100\%$

Whereby:

V = biofilter packing volume (m^3)

F = gas flow rate (m^3 h^{-1})

Ci = inlet concentration of pollutant (g m^{-3})

Co = outlet concentration of pollutant (g m^{-3})

3. Results

Overall, an average FOC value of 0.022g m^{-3} was observed from a range of 0.003 to 0.079g m^{-3}. As the experiment progressed, increases in the FIC resulted in increased FOC. Nevertheless, formaldehyde removal efficiency (FRE) by the vermicompost biofilter remained above 94.8% throughout the experiment (Table 1). Xu and coworkers also reported FRE of 95% for a biofilter using spider plant and composite packing material of compost, vermiculite powder and ceramic particles [10]. Another biofilter comprising golden pothos plants and a mixture of activated carbon and shale pebbles reported FRE of 98.7% at gas flow rate of 250m^3 h^{-1} [11].

Table 1: Effect of increasing formaldehyde inlet concentration on vermicompost biofilter performance at constant gas flow rate. Values given are averages ± standard deviation. FIC Formaldehyde inlet concentration; FOC formaldehyde outlet concentration; FRE formaldehyde removal efficiency; FLR formaldehyde loading rate; FEC formaldehyde elimination capacity.

Phase	1	2	3	4
FIC (g m-3)	0.443±0.11	1.056±0.15	3.746±0.43	5.897±0.50
FOC (g m-3)	0.021±0.01	0.006±0.005	0.016±0.011	0.027±0.022
FLR (g m-3 h-1)	20.8±5.2	49.6±7.0	176.1±20.2	277.3±23.5
FEC (g m-3 h-1)	19.9±5.4	49.4±6.9	175.4±20.4	276.0±23.3
FRE (%)	94.8±3.6	99.4±0.4	99.6±0.3	99.5±0.4

Removal efficiency does not take into account the environmental conditions of the biofilter, therefore the elimination capacity of a biofilter was introduced as a parameter to compare between research experiments carried out at different gas flow rates and biofilter volumes [12]. In this study, formaldehyde elimination capacity (FEC) is defined as the removal rate of formaldehyde per unit volume of biofilter packing. Referring to Fig. 2, the highest observed FEC was 276.0g m^{-3} h^{-1} at a loading rate of 277.3g m^{-3} h^{-1}. This value obtained was higher than the maximum FEC of 8.7g m^{-3} h^{-1} at the loading rate of 13.4g m^{-3} h^{-1} from research conducted by Xu et al. [10]. However, the finding from the current work is similar with work from another research group who investigated FRE and FEC of formaldehyde by inert packing material (i.e. lava

rock, perlite and activated carbon) inoculated with activated sludge. They reported maximum FEC values of 111.8g m^{-3} h^{-1} at a loading rate of 142g m^{-3} h^{-1}, occasionally reaching 180g m^{-3} h^{-1} during the experiment [13]. As a comparison, this investigated biofilter demonstrated FEC of 137.6g m^{-3} h^{-1} at loading rate of 138.5g m^{-3} h^{-1}. This indicated that the proposed biofilter could give better elimination capacity than composite packing material, and was comparable to inert packing material.

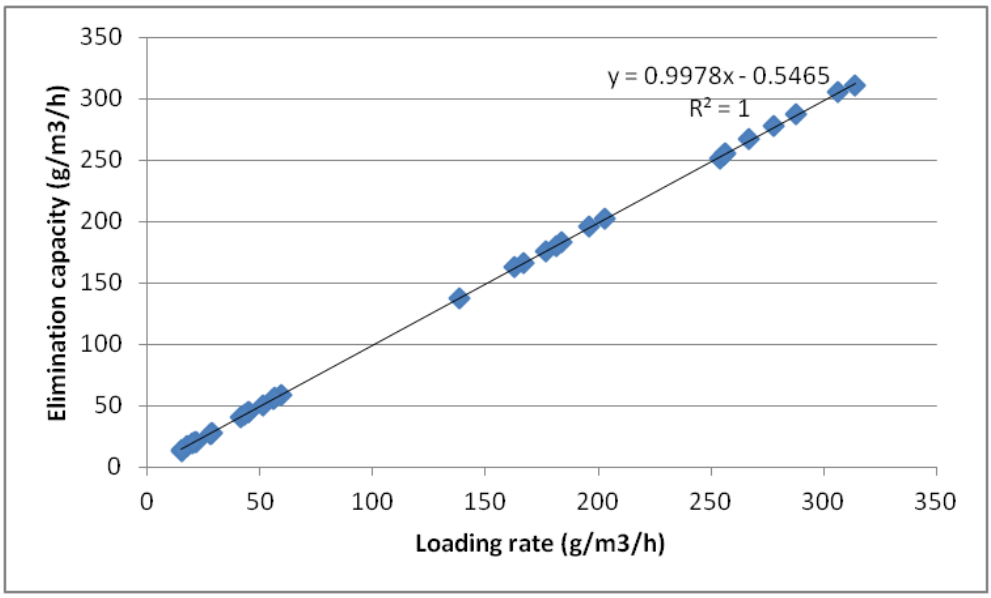

Fig. 2: Graph of elimination capacity versus loading rate

Moisture and small particle size play an important role in efficient mass transfer of formaldehyde from air stream to biofilm [11]. This feature is often exploited in biofilters to maintain maximum efficiency. However, the high FEC observed in the proposed biofilter suggests additional factors contributing towards the degradation of formaldehyde. Fungi and its extracellular enzymes are able to catalyse the oxidation of pollutant compounds [14]. The vermicompost utilized in the experiment was derived from spent mushroom compost, thus the presence of fungal spores and extracellular enzymes may have resulted in the accelerated FEC. Furthermore, plants absorb formaldehyde as a carbon source [15]. The golden pothos plant in the investigated biofilter was observed to thrive and increase in size during the experiment, indicating the sequestration of formaldehyde. Plant roots are presumed to maintain microbial diversity [16], thus the symbiotic role between plant and packing material can be tapped into to maintain overall wellbeing of biofilter.

4. Conclusion

The experiment demonstrated improved formaldehyde filtration performance through the incorporation of fungal- and phytodegradation strategies. Investigations revealed removal efficiency of formaldehyde above 95% with an outlet concentration range of 0.003 to 0.079g m^{-3}. The biofilter's high formaldehyde elimination capacity (276.0g m^{-3} h^{-1}) indicates potential application in the control of industrial formaldehyde emissions.

5. Acknowledgements

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