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Functional green wall development for increasing air pollutant phytoremediation: Substrate development with coconut coir and activated carbon

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ABSTRACT

Functional green walls are gaining attention due to their air cleaning abilities, however the air cleaning capacity of these systems may be improved through substrate modification. This experiment investigated the capacity of several green wall media to filter a range of air pollutants. Media, consisting of differently sized coconut husk-based substrates, and with different ratios of activated carbon were evaluated through the use of scaled down model 'cassettes'. Tests were conducted assessing each substrate's ability to filter particulate matter, benzene, ethyl acetate and ambient total VOCs. While the particle size of coconut husk did not influence removal efficiency, the addition of activated carbon to coconut husk media improved the removal efficiency for all gaseous pollutants. Activated carbon as a medium component, however, inhibited the removal efficiency of particulate matter. Once the substrate concentration of activated carbon approached ∼50%, its gas remediation capacity became asymptotic, suggesting that a 50:50 composite medium provided the best VOC removal. In full-scale botanical biofilter modules, activated carbon-based substrates increased benzene removal, yet decreased particulate matter removal despite the addition of plants. The findings suggest that medium design should be target pollutant dependent, while further work is needed to establish plant viability in activated carbon-based media.

1. Introduction

There is a growing need to enhance indoor air quality and maintain it at acceptable levels through energy efficient technologies [1,2]. In recent decades, significant research has demonstrated the potential of potted-plants to remove a range of volatile organic compounds (VOCs) [3–9], with the mechanism of removal largely attributed to microbial degradation of pollutants that diffuse into the potted-plant substrate [4,5,7,8]. The efficacy of potted-plants notwithstanding, their application for VOC removal *in situ* may be less efficient than demonstrated in many laboratory studies, due to pollutant removal capacity overestimates stemming from the use of small test chambers with high concentrations of pollutants [10].

Green wall technology, specifically active botanical biofiltration, builds upon the remediation capacities of potted-plants through the use of active airflow to the substrate, and greater plant density for a given floor area [11]. In these systems, the volume of polluted air to which the system is exposed is increased by actively drawing air through the substrate, which is kept moist by regular irrigation. In doing so, polluted air is drawn through the porous substrate, which supports a microbial population capable of VOC degradation [12]. In this process, gaseous pollutants are removed in three steps: firstly, they are transferred from the gas phase to the liquid film within the biofilter; secondly, pollutants diffuse within the film; and finally, pollutants diffuse to substrate microbial cells where they are degraded, or are otherwise adsorbed onto the packing material of the biofilter [13]. It is therefore advantageous to use relatively porous materials with large surface areas to increase liquid film area, reduce the diffusion pathway length between film and adsorption site, and to increase the number of adsorption sites [14].

Studies of other vegetated filtration systems have demonstrated that media plays a critical role in their functionality, as the substrate not only provides the physical support for plants, but facilitates the primary removal processes for pollutants. Green wall systems designed specifically for pollution removal have focused on the use of use coco-coir [15,16]. However, it is unclear how this media would perform under varying pollutant loading of different pollutants. Prodanovic et al. [16] investigated the processes that govern pollutant removal performance

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of coir media in green walls and suggested that a combination of coir with adjunct substrates might prove to be the best option for optimal application in green walls for pollutant removal.

Previous studies have highlighted activated carbon as an excellent adsorbent for VOCs in botanical [3,17] and microbial biofilters [18–22]. While activated carbon is known to be an effective substrate in microbial biofilters, its application in botanical biofilters requires it to also provide conditions that support plant health. Aydogan and Montoya [3] trialed a number of novel substrates for VOC removal and found a substrate consisting of wetted activated charcoal removed formaldehyde efficiently, but could not sustain long term plant health. Wang and Zhang [17] developed a botanical air filtration substrate composed of a 50:50 mix (by volume) of shale pebbles and activated charcoal, recording high removal rates for formaldehyde and toluene, however it was unclear which substrate components were responsible for the VOC removal. Furthermore, activated carbon-based botanical biofilters have not previously been assessed for their particulate matter (PM) filtration capacity, thus further research is needed before such systems can be comprehensively evaluated for practical use in air cleaning systems that target multiple pollutants.

The addition of activated carbon to the plant growth substrate in a botanical biofilter system may substantially enhance these systems' potential to efficiently remove gaseous pollutants. Research is, however, required to assess the quantitative effects of the addition of activated carbon. The research presented here aimed to optimize the pollutant removal capacity of an existing botanical biofilter system through substrate modifications. This was achieved by characterizing the benzene, ethyl acetate, ambient TVOC and PM single pass removal efficiency (SPRE) performance of three sizes of coconut husk biofilter substrates. Then, using the best performing substrate size fraction with the incorporation of activated carbon adsorbents, further possible improvements in pollutant removal were tested. Finally the best performing substrate identified was tested in a full-scale botanical biofilter with plants, using the species *Nephrolepis exaltata bostoniensis,* as this species has previously been identified as an efficient phytoremediator of PM [23] and VOCs [7,24].

2. Methods

2.1. Test cassettes

To test the effectiveness of different substrates on reducing VOC and PM, substrate cassettes were designed to facilitate the use of a large number of fully independent replicates (Fig. 1). Previous work has shown that repeated exposure of the plant/microbe system to VOCs enhances draw down rates [25], and thus would introduce severe carry over effects if samples were used more than once. Further, it has been demonstrated that the performance of air cleaning media at repeated doses of VOCs cannot directly reflect their performance at typical indoor concentrations [25].

Cassettes were constructed from PVC piping (85 x 85 mm, 482.1 cm^3). Media were encased within a loose weave high-density polyethylene (HDPE) membrane within the PVC housing unit. A diameter of 85 mm was chosen to match the air intake inlet of a green wall module that has previously been tested for air pollutant remediation [23,26,27], while an 85 mm depth corresponds to the approximate shortest horizontal airflow path length through these green wall units, thus this design reflected airflow that followed the path of least resistance through the central outlet at the front face of the green wall unit; resulting in a conservative estimate of system performance.

2.2. Medium combinations tested

2.2.1. Coconut husk-based media

Three different sized fractions of coconut husk-based media were trialed, with each treatment independently replicated 6 times (Fig. 2). These consisted of a fine fraction (coir fibers with a diameter of ~0.5 mm), a medium fraction (particles of 5–15 mm) and a coarse fraction (particles of 8–35 mm). Coconut husk has been used in several functional green wall studies, with the literature thus far indicating that it is a functional substrate for active green walls and is capable of serving as packing media in biofilters. Coconut husk used in biofilters typically has a water content of 72.5%, is 95% organic matter, has a specific surface area of 0.75 m^2/g, and has a water holding capacity of 5.5g[H20]/g dry material. All media were packed to a density equivalent to that used in green wall modules. Media were tested for air pollutant removal after saturation to field capacity and draining overnight.

2.2.2. Carbon based media

Using the results from Section 2.2.1, the highest performing coconut husk substrate was used for a series of trials that incorporated differing proportions of granular activated carbon (GAC; EA1000 4 mm; Activated Carbon Technologies Pty Ltd, Melbourne, Australia). This GAC is specifically made for the removal of atmospheric VOCs, and is manufactured from steam-activated coal, producing a large surface area and high degree of microporosity [28]. Typical analysis provided by the manufacturer for the activated carbon indicates the apparent density is 0.45-0.50 g/mL, moisture as packed is 2%, surface area is 1000m^2/g min, and carbon tetrachloride activity is 65% min. The following ratios of coarse coconut husk to GAC by volume were assessed: 0:100, 10:90, 20:80, 30:70, 40:60, 50:50, 60:40; with the coarse coconut husk and GAC having bulk densities of ~0.20 g/cm^3 and ~0.52 g/cm^3 respectively. Each ratio was replicated 4 times. Prior to cassette construction, the GAC was rinsed thoroughly with water to remove residual fine particles. Before testing, all substrate media used in the experiments were watered to field capacity (the maximum volume of water the substrate can hold) and left to drain overnight.

2.2.3. Full-scale botanical biofilters

In order to produce practical outcomes for the horticultural infrastructure industry, the air cleaning potential of the optimized system

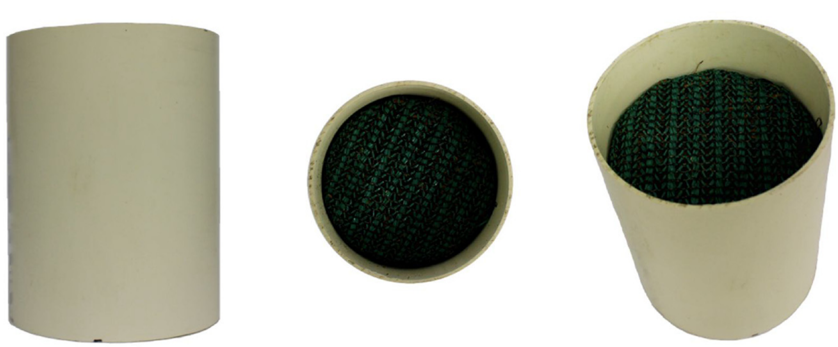

Fig. 1. Cassettes that contained the test substrates.

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