The influence of plant density on the removal efficiency of volatile organic compounds in indoor air using a biological filter

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ABSTRACT. A major health issue in indoor environments is the accumulation of volatile organic compounds (VOC). Biofiltration has been proposed to remediate VOC contaminated indoor air. The operational parameters of a novel biofilter which integrates green plants into the system was tested. Biofilters were challenged with Methylethylketone (MEK). The density of plants in a biofilter had a significant effect on the removal efficiency of MEK. Under the low mineral nutrient conditions, there was a positive relationship between plant density and MEK removal efficiency when plant density was less than 5 plants per $15m^2$ of filter media. A negative relationship between removal efficiency and plant density existed when plant density was greater than 5 plants per $15m^2$. Because higher plant densities were not associated with improved performance, negative plant-microbes interactions could have occurred. After mineral nutrient content of the circulating solution was increased, there was a positive relationship between removal efficiencies and plant density suggesting positive plant microbe interactions could have occurred. The amount of nutrient incorporated by the plants and microbes in the system has no relationship with the removal efficiency. The final root and shoot mass had a positive relationship with removal efficiency of MEK.

1 INTRODUCTION

As a society we spend as much as 80 to 90% of our time indoors, therefore the quality of indoor air is a major concern (Jenkins *e al*., 1992). A major health issue in indoor environments is the accumulation of contaminants such as volatile organic compounds (VOC). VOC concentrations result from the presence of a wide variety of synthetic and natural products, the occupants and their activities. VOC's reported to occur indoors include a large variety of aliphatic hydrocarbons; aromatic hydrocarbons; oxygenated hydrocarbons and halogenated hydrocarbons (Godish, 2001) VOC concentration can vary spatially and temporally (Spengler *e al*., 2001). Total VOC concentrations indoors typically range from 50 to 1000 ug/m^3 and can reach hundreds of mg/m^3 for periods of minutes or hours (Spengler *e al.,* 2001). Many common indoor VOCs have been linked to both acute and chronic health conditions associated with sick building syndrome (Hansen, 1999; Godish, 2001).

Biofiltration has been proposed as a means of avoiding accumulation of VOCs indoors (Darlington *et al*., 1998; Darlington *et al*., 2001). Biofiltration technology is commonly used to aid industry to comply with environmental regulations by remediating industrial waste gas streams. In industrial waste gas streams, biofilters deal with relatively high concentrations of VOCs (Devinny *et al*., 1999). However, indoor air is often contaminated with a wide diversity of contaminants at very low concentrations of pollutants (by industrial standards) (Spengler *et al*. 2001). To address this unique environment a novel biofilter which integrates green plants into the system has been proposed (Darlington *et al*., 1998; Darlington *e al*., 2001).

To effectively remediate indoor air, the operational parameters of the indoor air biofilter system must be understood. Past research has been conducted under the assumption that the observed removal efficiency of an indoor air biofilter is directly related to a plant microbe interaction. Plants in the biofilter serve to increase the size and diversity of the degrading microbial community. Some of our earlier work indicated a negative relationship exists between plant density and removal efficiency (Shome, 2004). However, it is possible that competition for resources such as mineral nutrients between degrading microbes and plants are limiting the ability of the microbial community to degrade VOCs effectively.

2 MATERIALS AND METHODS

Six individual, lab scale biofilters were tested in a partially sealed, 65 m^3 laboratory, located at the University of Guelph, Ontario, Canada. Biofilters were exposed to a 24 hour light regime of approximately 65 µmol m^{-2} S^{-1}. Each biofilter was composed of two layers (each c.a. 2.4 cm thick) of synthetic polyester weave material (Air Quality Solutions Ltd, Guelph, ON) within a 0.36m x 0.50m square plenum. All biofilters had a surface media surface area of 0.15 m^2. The media was constantly wetted with circulating nutrient solution.

For the first 20 days of the experiment the nutrient solution consisted of only deionised water. After this point the nutrient content of the solution was increased to 075 g/L N with Plant Products Hydroponic Plant Food (N.P.K.18-9-27). The nutrient content was restored every second day according to electrical conductivity and totally replaced every 10 days until the end of the experiment. Room air was drawn through the biofilter media at a constant air flux of 0.5m s^1. Biofilters were planted with bare rooted *Chlorophytum capense* (spider plant). The number of plants per biofilter was 0, 1, 1, 3, 5 and 7 plants. Dry weight of root and shoots were taken upon completion of study.

A SRI model 9300A gas chromatograph (GC) was used to monitor VOC concentrations in the ambient air and the effluent stream of each biofilter (described in detail by Darlington *et al*., 2001). The GC sampled the effluent of each biofilter 3 times per hour and the influent 9 times per hour. This provided real time data of VOC concentrations within the room. The room (influent) VOC concentrations were controlled by a feedback controller dosemeter. TMethylethylketone (MEK) used as test VOC. -MEK concentration followed a diurnal pattern with concentrations ranging from 10 (midday) to 120 ppbv at mid night. This diurnal pattern more closely reflects the fluctuations seen in indoor air streams.

Data analysis was accomplished using a regression analysis with SAS v8 for windows. The resultant removal efficiencies per day were averaged over 20-day periods and plotted against plant density and nutrient levels. The final plant biomass was only considered for the last period's removal efficiency.

3 RESULTS AND DISCUSSION

The biofilters were able to remove substantial amounts of VOCs. Under low mineral nutrient conditions, the density of plants in a biofilter had a significant effect on the removal efficiency of MEK (Figure 1). There was a positive relationship between plant density and MEK removal efficiency when plant density was less than 5. However, a negative relationship between removal efficiency and plant density existed when more than 5 plants per biofilter were present, ion (levelling offAt these higher densities, the benefits of adding another plant to the biofilter were apparently outweighed by the costs associated with the addition of another plant.

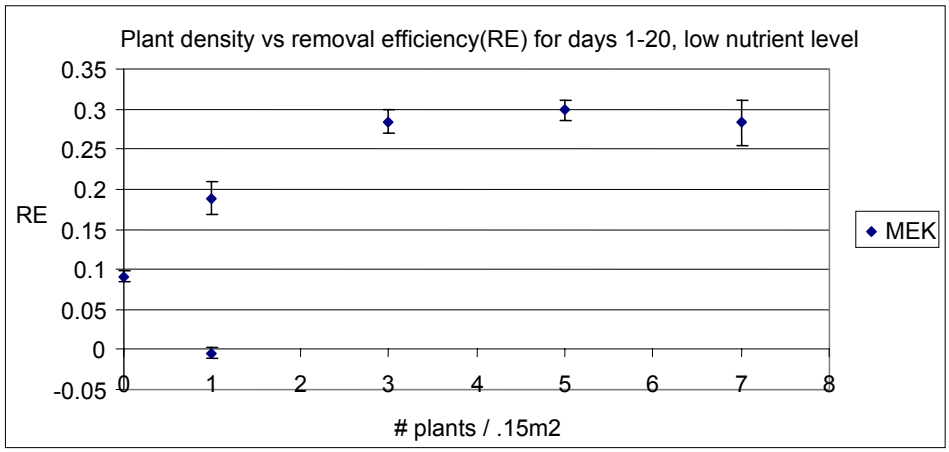

Figure 1. At low nutrient level, biofilters removed substantial amounts of Methylethylketone. At a plant density less than 5, there is a positive relationship between removal efficiency and plant density. At plant density greater than 5 the relationship is negative. Error bars indicate the standard error of the mean.

The role of mineral nutrition was investigated by increasing the N.P.K content of the circulating solution. After mineral nutrient content of the circulating solution was increased on day 20 from 0.000 to 0.075 g (N)/L, there were increasing removal efficiencies with increasing plant density. It is interesting to note that during this period, however, there was no substantial difference in the removal rates for biofilters with plant densities less than three plants per biofilter. Figure 1 and illustrate the dependence of MEK removal on plant density.

When considering the addition of green plants alone to the biofiltration system, there was a clear increase in the removal efficiency with the lower densities of the plants (Figure 1). This increase was likely due to the plants creating a rhizosphere more conducive to growth of the degrading microbes, similar to changes reported during phytoremediation (for review see McCutcheon *et al.,* 2003). Plants increase the catabolic capacity of soil independent of contaminants (Nichols *et al*., 1997; Haby *et al*., 1996). During phytoremediation, the inclusion of green plants in contaminated soils improves the activity of beneficial microbes by influencing the local geochemistry, availability of water and nutrients (including organic molecules) and the local microclimate of the rhizosphere and senescence of roots (McCutcheon *et al*., 2003). This increase in organic content contributes to an increase in the overall microbial

density and therefore an increase in the number of beneficial microbes present. In this specific application, the 'soil' is the biofilter media.

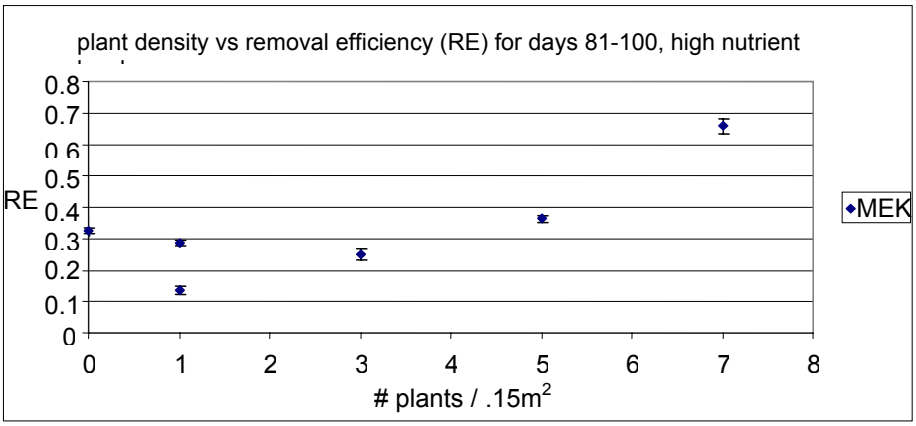

Figure 2. When both plant density and nutrient level was high, a positive relationship between plant density and removal efficiency was observed. When plant density was 3 or less, no significant difference was observed. Error bars indicate the standard error of the mean.

Alternatively, the inclusion of specific green plants in phytoremediation application can lead to a genetic shift in the microbes present rather than a simple increase in numbers present. Theplants have the ability to influence the overall size and functional composition of the microbial community in the rhizosphere, and (Siciliano *et al*., 2003). For example, plants of. They the ability to influence the relative abundance of genes that are relevant for the degradation of toxic organics in the microbial community in the rhizosphere (Siciliano *et al*., 2003). Thus, plants can influence the number and type of degraders present in the rhizosphere.

Degradation of biofilter media has been noted as a major factor in biofilter performance. In organic bed biofilters, the biofilter media is a source of nutrient that can be exhausted (Devinny *et. al*., 1999). The biofilter media used in these experiments was entirely synthetic, with no initial source of carbohydrates for the microbes and hence prone to organic starvation. The inclusion of green plants would supply a renewable source of organics to the biofilter to overcome this limitation.

However, under the low mineral nutrient conditions higher plant densities were not associated with improved performance, suggesting negative plant-microbes interactions. Since this negative interaction was reversed by the addition of mineral nutrients, it is likely that under low nutrient conditions the microbes were unable to compete effectively with the plants and exhibited suppressed activity.However, when mineral nutrients were not limiting there was a positive relationship between plant density and biofilter performance. The high nutrient and low plant density condition may have encouraged the growth of other plants such as algae which may have similarly increased performance. Under higher plant densities, these lower plants may have been unable to establish due to shading by the spider plants.

The amount of nutrient incorporated by the plants and microbes in the system has no relationship with the removal efficiency of the system for (Figure 3). It is likely that

because sufficient mineral nutrients were maintained in the system, mineral nutrients did not become a limiting factor. The plants and degraders in each biofilter were able to fill their nutrient requirements with minimal limitation. Thus, mineral nutrients did not limit the rate that degrading microbes operated in this system.

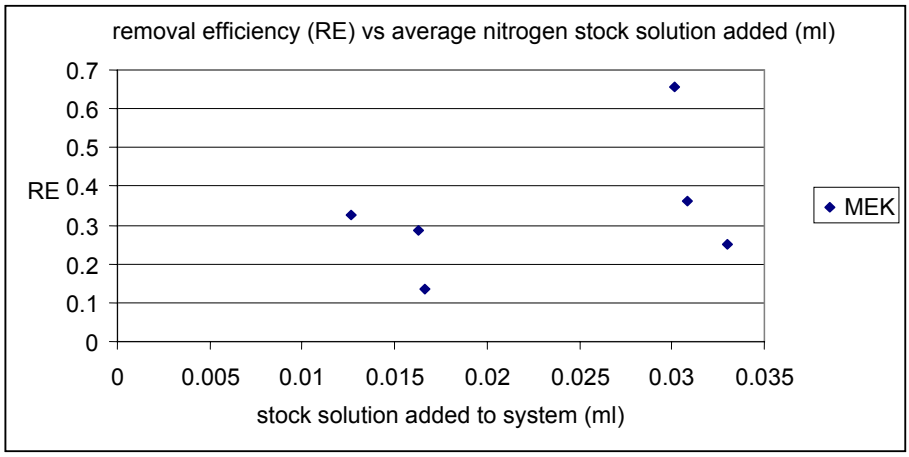

Figure 3. Graph of stock solution added per day *vs* removal efficiency from days 81-100. No significant relationship was observed.

The final root and shoot mass had a positive relationship with removal efficiency of . This result is contradictory to the findings of Shome (2004). She found a negative correlation between plant root biomass and removal of . This is likely due to the difference in nutrient availability between the two studies. There was likely competition for nutrients in Shome (Shome, 2004). However, since ample nutrient was present in this study the addition of plant biomass resulted in an increase in removal.

When an indoor air biofilter is used for removing and eliminating VOCs from indoor air a level of nutrient should be maintained that is sufficient to prevent competition between plants and microbes. If sufficient mineral nutrients are present in the system, a high plant density was highly beneficial and resulted in increased removal efficiency. However, if mineral nutrients do become limiting, a high plant density will decrease the effectiveness of the biofilter at remediating indoor air.

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