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INNOVATIVE USES OF BIOCHAR AS CARBON SEQUESTERING BUILDING MATERIALS IN WALL PLASTER AND PELLETS

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Abstract

Biochar has recently been explored as an alternate construction material. While it has been deployed as road construction, there is an emerging trend of using biochar as concrete admixture and other non-structural building elements. This study explores the use of biochar as a component in wall plaster and pellets that are used to fill cavities for interior non-structural wall panels. Biochar was incorporated in plastering material and the carbon dioxide adsorption capability of this material mix was compared to that of control samples (made up of pure plaster). It was found that biochar increased the net carbon dioxide adsorption capability by more than four times. However, contrary to claims in the literature, we found no evidence that the biochar in this mixture can significantly remove total volatile organic compounds from the indoor air. In a separate study, biochar was used to coat pellets that were used to fill cavities in cavity wall. The biochar was found to increase the net carbon dioxide adsorption capability by about six times (compared to control samples, which were plaster pellets without biochar coating). There was also no significant adsorption of total volatile organic compounds. These results indicated clearly that biochar can be effective as a regulating agent for indoor carbon dioxide level, which is one of the main determinant factors for the infamous Sick Building Syndrome.

Keywords:

Biochar; wall plaster; biochar pellets; cavity walls; carbon sequestration

1 INTRODUCTION

Awareness on the issue of indoor air quality in Singapore increased in the past few years, and more resources have been channeled to better understand these issues in the local context (Chan, 1999; Chan, et al., 1995; Ooi et al., 1995; Sekhar et al., 1997; Tham et al., 1997). Alongside the concern for greenhouse gas abatement in Singapore, the highly dense built environment has also triggered a concern that the amount of indoor carbon dioxide (CO_2) may increase to unhealthy levels (ENV, 1996). Related to the infamous Sick Building Syndrome, high indoor CO_2 can trigger a number of physiological reactions, including dizziness, fatigue, headaches and even death (Farrar et al., 1999). As such, given that CO_2 and volatile organic compounds (VOCs) are two of the most significant sources of indoor pollutants (Torpy, 2013), this study focused on how indoor CO2 and TVOC levels can be regulated

Biochar has been identified as one of the possible solutions to tackle climate change through Carbon Capture and Storage (CCS) (Ghani, 2014). Biochar is also believed to be able to remove impurities from the polluted air (Hertsgaard, 2014). Therefore, given that biochar has the potential to perform the dual function of CCS and removal of impurities, this study explored the deployment of biochar as a kind of building material, while performing these functions to improve indoor air quality.

2 LITERATURE REVIEW

Biochar is a product of thermal transformation of organic materials under absence or low oxygen concentration, using methods such as pyrolysis or gasification. Common sources of biomass includes wood chips, grass residues, manures, nutshells, biomass crops and rice residues (Cox, et al., 2012; Pro-Natura International, 2015). Biochar is relatively well understood as a soil enhancement. Recently, it has been explored as a construction material (Gupta and Kua, 2016; Gupta and Kua, 2017). While works had been conducted on deploying biochar for road construction, there is an emerging trend of using biochar in concrete. In comparison, using biochar this way will reduce more greenhouse gas emissions than if carbon is captured and sequestered through mineralization in general. The use of biochar-containing construction materials to capture and then “lock” atmospheric carbon dioxide in building and structures can potentially reduce greenhouse gas emissions by additional 25%. Gupta and Kua (2016) focused on evaluation biochar’s capability for carbon adsorption, which depends on factors such as pyrolysis conditions (specifically, pyrolysis temperature, heating rate and pressure) and activation methods (and without surface modification). Several suggestions were proposed by the authors to deploy biochar as a building material; for example, biochar can be saturated with CO_2 before being added into concrete mixture, thus "locking" the captured CO_2 within these buildings and structures. Such a concept may pave the way for huge volume of greenhouse gases to be captured and stored for long term.

Life cycle assessments have shown that biochar has net negative intensity [Budzianowski, 2012; Ibarrola, 2012]. Specifically, Ibarrola [2012] found that slow pyrolysis systems can potentially abate carbon of between 0.07 and 1.25 tonnes of CO_2 eq. per tonne of feedstock treated, whereas other groups found an abatement range of 0.7–1.3 tonnes of CO_2 equivalent per oven dry tonne of feedstock processed [Hammond, 2011].

3 METHODOLOGY

3.1 Sample preparation

The biochar used was made from a feedstock of mixed horticultural waste collected from tree pruning in Singapore. The feedstock was subjected to gasification under a temperature range of 550 ˚C to 600 ˚C. The biochar flaks were grinded or pounded into powder form using a hammer or brick and a sieve. 40 kg of cementitious plastering material known as BUILDERSmart© was mixed with water to form a slurry in a water-plaster ratio of 1:3. Before the biochar was deployed in the plaster, it was desorbed in a furnace at 500oC for 2 hours. This mixture was rolled into rounded pellets and coated with a layer of the grinded biochar powder.

Cavity wall samples measuring 29 cm-by-35.5 cm were made using two panels of plywood positioned at two different distances apart. The biochar pellets made were contained in this cavity. Holes were drilled on these panels to expose the pellets to the surrounding. A thin layer of wire mesh are attached to the inner surfaces and on the sides of the plywood panels to hold the two panels in place.

Two types of biochar plaster were produced – the first type was formulated by spraying a pre-defined quantity (6 g) of biochar over a freshly plastered wall with a spray gun (this is herein labelled as "spray-on biochar plaster"); the second type was a mixture of the biochar powder in the pre-mixed plaster matrix (herein labelled as "pre-mixed biochar plaster"). In all these samples, the quantities of biochar, pre-mix plaster and water were fixed at 6 g, 210 g and 70 ml respectively. The wall samples for this part of the study were made from single panel plywood.

3.2 Carbon dioxide and Total Volatile Organic Compounds measurements

The experimental procedures for the experiment are as follow:

- For both types of experiments, the wall sample was placed vertically inside the tank, positioned nearer to one side of each tank (as shown in Fig.s 1 and 2). A fan (to circulate the air flow) and CO_2 analyzer (Telaire 7001) or ppbRAE 3000 TVOC meter were also placed inside each tank.
- In the experiments involving pellets, the wall cavity was filled with biochar pellets or plaster pellets (as control samples). For the plaster experiments, the plaster was applied to one side of the plywood (on the side facing the detector; refer to Fig. 2).
- When the tanks were then tightly sealed, pure CO_2 or TVOC (from a commonly used insect repellent) was introduced into the tank through a tube until the interior CO_2 concentration reaches around 500 or 1,000 ppm or TVOC concentration reaches around 400 or 3,000 ppb (see tables 1 and 2).
- Readings of the CO_2 or TVOC concentrations were recorded manually at 5 minutes interval for 2 hours.
- Steps (a) to (d) were repeated for another two trials each for the different sets of conditions shown in tables 1 and 2. Control experiments involving either plaster pellets or pure plaster – both without any biochar – were also conducted in triplicate. These readings were subtracted away from the measurements recorded in (d) above to derive the adsorption due to the biochar.

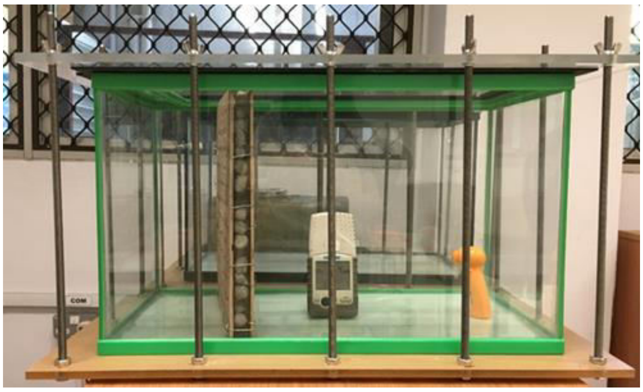

Fig. 1. Basic experimental setup for studying different types of pellets. In this case, only the carbon dioxide analyzer (Telaire 7001) was shown.

Fig. 2. Basic experimental setup for studying different types of plaster. In this case, only the carbon dioxide analyzer (Telaire 7001) was shown.

The reason that 500 and 1,000 ppm were chosen as starting concentrations was that 500 ppm was the average indoor CO_2 concentration, whereas 1,000 ppm was the maximum allowable indoor concentration in Singapore.

Table 1. Experimental conditions for measuring the carbon dioxide and total volatile organic compounds of biochar pellets and pure plaster pellets (control) in cavity wall.

Width of wall cavity	Starting carbon dioxide concentration	Starting TVOCs concentration
30 mm	500 ± 20 ppm	200 ± 20 ppb
	1,000 ± 40 pm	1,800 ± 50 ppb
15 mm	500 ± 20 ppm	200 ± 20 ppb
	1,000 ± 40 pm	1,800 ± 50 ppb

Table 2. Experimental conditions for measuring the carbon dioxide and total volatile organic compounds of different types of plaster.

Types of plaster	Starting carbon dioxide concentration	Starting TVOCs concentration
Spray-on biochar plaster	500 ± 20 ppm	200 ± 20 ppb
	1,000 ± 40 pm	1,800 ± 50 ppb
Pre-mixed biochar plaster	500 ± 20 ppm	200 ± 20 ppb
	1,000 ± 40 pm	1,800 ± 50 ppb

4 RESULTS

As shown in the graphs in Fig. 3, biochar pellets increased rates of CO_2 adsorption significantly, compared to the control samples; adsorption of CO_2 by the control samples is caused by the carbonation of the cementitious plastering material. Comparing the graphs in Fig. 3(a) with 3(c), and 3(b) with 3(d), it is clear that doubling the width of the wall cavities increased the CO_2 adsorption rate by about 5 times. In totality, these results indicated that biochar coated pellets have the ability to absorb CO_2 at the rate of 8 – 4,000 ppm/min. Using Ideal Gas equation, it was estimated that the biochar pellets recorded a CO_2 adsorption rate of 0.033 mmol/g of biochar. However, it was also found that these pellets did not significantly adsorb the TVOCs introduced into the tanks; these results are illustrated in Fig. 4.

The graphs in Fig. 5 show that spray-on biochar plaster adsorb CO_2 significantly faster than the control samples and pre-mixed biochar plaster. The advantage of the spray-on biochar plaster becomes more distinct at higher starting CO_2 concentration. Using Ideal Gas equation, the CO_2 adsorption were found to be 0.138 and 0.055 mmol/g of biochar for the spray-on biochar plaster and pre-mixed biochar plaster respectively.

Similar to the results for biochar pellets, biochar-containing plaster did not show any significant adsorption of TVOCs in our experiments.

5 SUMMARY AND CONCLUSION

Results obtained from this study showed the potential of biochar as a carbon sequestration material for regulating indoor CO_2 level, when deployed as either a plastering material or in the form of pellets contained in cavity walls. This study focused on a single-cycle of adsorption; confirmation of the full CO_2 adsorption ability of these biochar-based building materials will be possible by measuring their multiple-cycle adsorption – in which CO_2 is channeled into the tanks until the biochar within reaches saturation.

Another important result of this study is refuting the common claim that biochar can remove TVOCs. The null result is due to the fact that the non-functionalized and unactivated biochar used in this study do not contain the right kinds of functional groups to adsorb the key components of TVOC contained in the insect repellent sprays, including biphenyl and chlorophenols. Future studies should focus on functionalizing biochar specifically with these functional groups and quantifying its rate of TVOC adsorption.

6 ACKNOWLEDGMENTS

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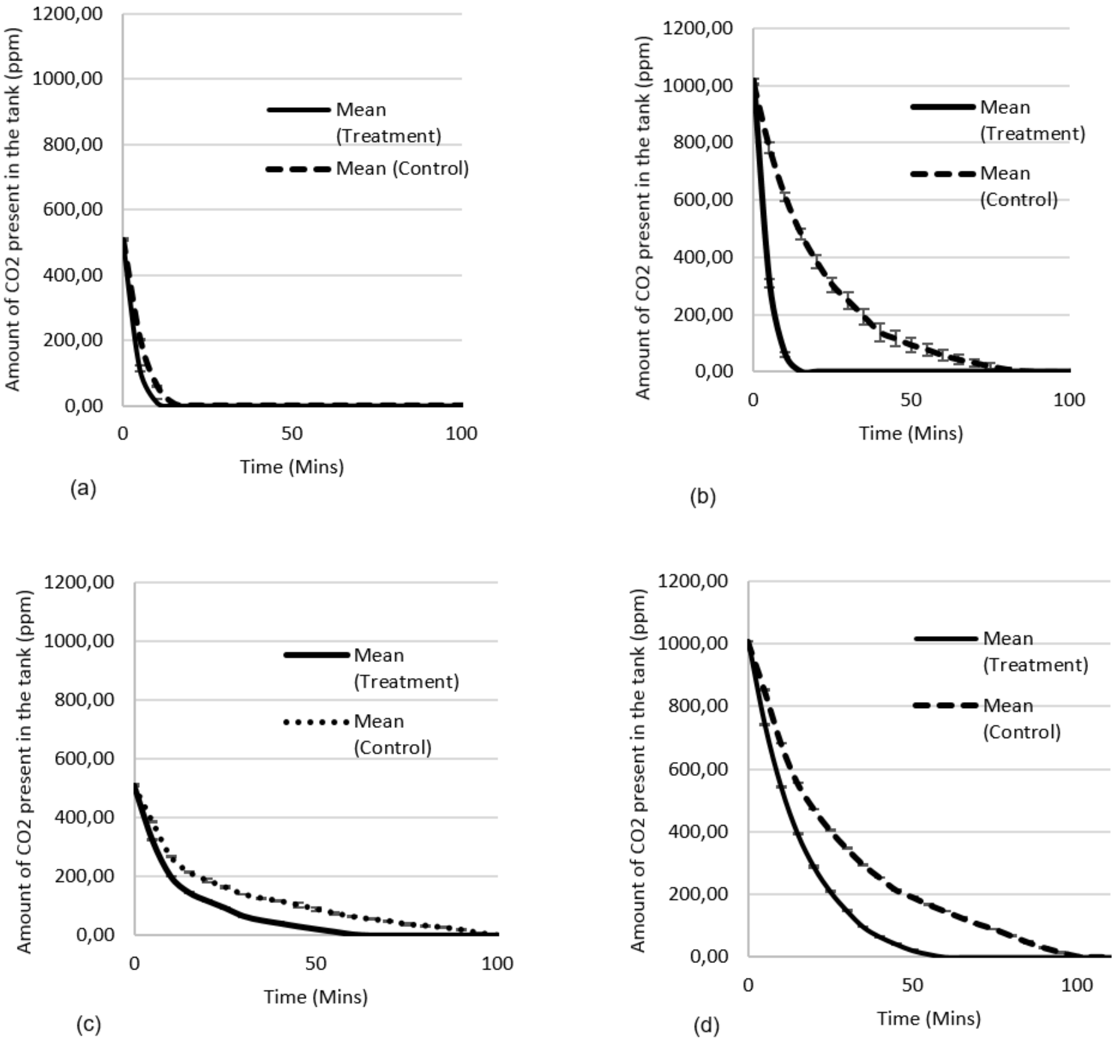

Figure 3. Comparison of carbon dioxide adsorption rates of different types of walls containing biochar pellets with their respective controls. (a) and (b) represent walls with 30mm cavities, whereas (c) and (d) represent walls with 15mm cavities. The values shown in the graphs have been modified for air leakage from the tanks.

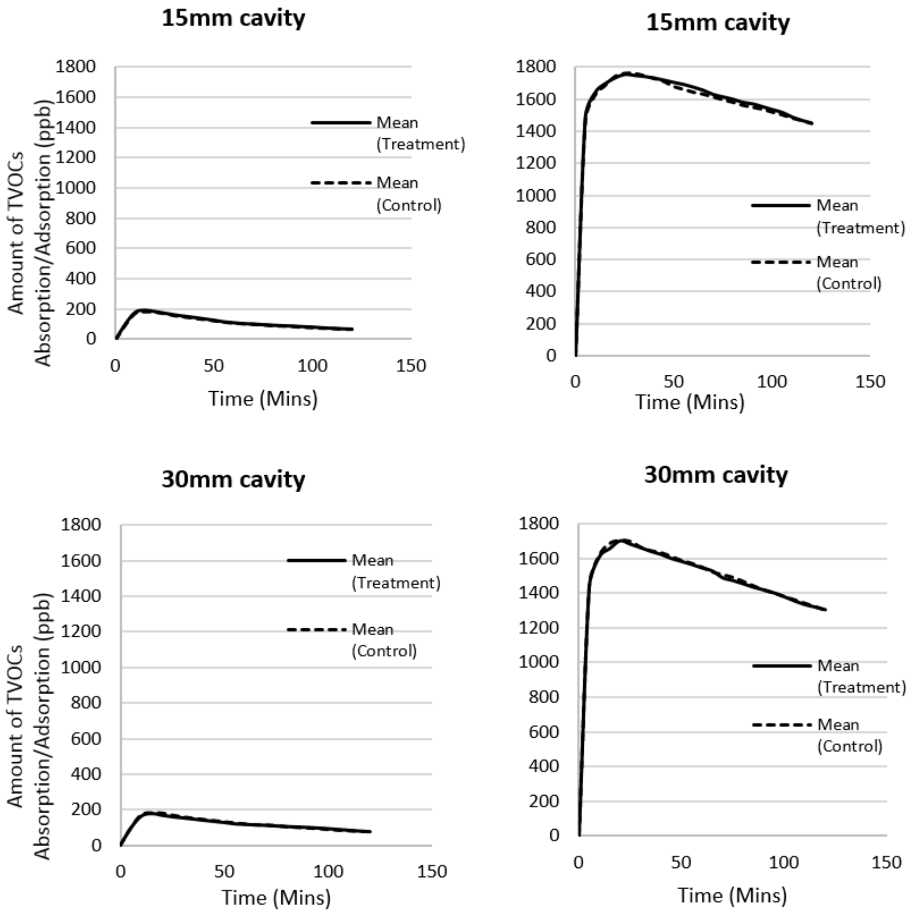

Figure 4. Comparison of adsorption rates of total volatile organic compounds by biochar pellets in the different types of cavity walls with those of their respective controls.

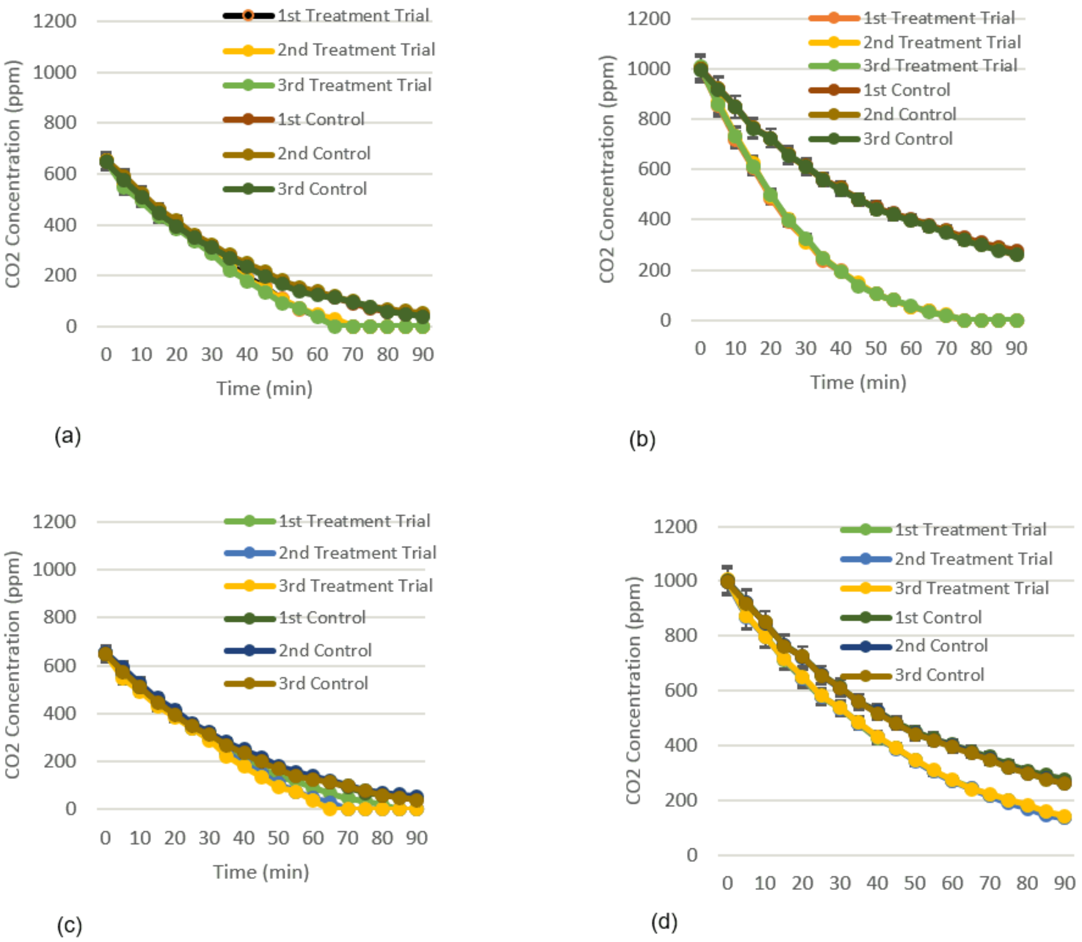

Figure 5. Comparison of carbon dioxide adsorption rates of spray-on biochar plaster (a and b) and pre-mixed biochar plaster (c and d) with those of the control (pure plaster). The values shown in the graphs have been modified for air leakage from the tanks.