

Abstract

The rapid increase in atmospheric carbon dioxide and its adverse effects on the climate have pushed scientists to develop solutions to reduce carbon emissions and decrease carbon dioxide levels. One possible solution is a combination of two carbon dioxide removal (CDR) technologies: direct air capture (DAC) and biochar/activated carbons (ACs). DAC is a technology that directly reduces the atmospheric carbon level by capturing CO₂ from ambient air and storing it via long term sequestration. Biochar/ACs are a carbon negative product produced by pyrolyzing biomass. While biochar/ACs are effective in numerous environmental applications, such as soil enhancement, heavy metal waste remediation, and mitigation of greenhouse gas emissions, this research focused on the application of biochar/ACs as a DAC sorbent.

This study investigated the impact of pyrolysis conditions – pyrolysis temperature, pre-drying feedstocks, and nitrogen gas flow rate – on the subsequent biochar CO₂ adsorption capacity. Increasing pyrolysis temperature from 500 to 800 °C increased the CO₂ adsorption capacity of walnut biochar by 105%. The impact of pyrolysis temperature on CO₂ for walnut biochar was determined to be linear ($R^2 = 0.999$), which was in contrast to previous studies. Increasing pyrolysis temperature from 500 to 800 °C resulted in a consistent increase in adsorption capacity for all feedstocks tested, however, the impact of pyrolysis temperature was shown to vary with feedstock selection. There was a correlation between the feedstock lignin content and the increase in adsorption capacity such that higher lignin content led to a more significant impact of pyrolysis temperature ($R^2 = 0.955$, $p = 0.03$). This correlation may be due to how lignin decomposes at higher temperatures, as the decomposition of lignin is largely responsible for the development of pores during pyrolysis.

Pre-drying feedstocks before pyrolysis via vacuum desiccation decreased the CO₂ adsorption capacity of walnut biochar by an average of 42% across four pyrolysis temperatures, indicating that although pre-drying is a common production step, it significantly decreases biochar adsorption. Pre-drying feedstocks also resulted in a consistent decrease in adsorption capacity for all feedstocks pyrolyzed at 500 °C and 800 °C. There was a negative correlation between feedstock moisture content and the impact of pre-drying such that feedstocks with low moisture content experienced a larger decrease in adsorption capacity due to pre-drying ($R^2 = 0.960$ for 500 °C; $R^2 = 0.992$ for 800 °C; $p = 0.03$). Contrarily, there was a positive correlation between feedstock lignin content and the impact of pre-drying such that the feedstocks with higher lignin content experienced a larger decrease in adsorption capacity due to pre-drying ($R^2 = 0.982$ for 500 °C; $R^2 = 0.869$ for 800 °C; $p = 0.04$). This correlation can be explained by the reaction mechanism during pyrolysis, as hydrolysis plays a significant role in the decomposition of lignin.

The impact of increasing nitrogen gas flow rate was shown to increase CO₂ adsorption capacity depending on the feedstock, as increasing nitrogen gas flow rate was only shown to significantly impact two of the four feedstocks tested: walnut and coconut. For walnut biochar, increasing the flow rate from 85 to 200 mL/min increased the adsorption capacity by 21.1%, indicating that nitrogen flow rate is another important variable to optimize for biochar production. Additionally, for walnut biochar, there was an optimal flow rate of 200 mL/min that maximized adsorption capacity. Increasing the flow rate from 85 to 200 mL/min also increased the adsorption capacity for coconut samples by 28.6%, but had no significant impact on the adsorption capacity for sawdust or corn cob samples. These results may be attributed to the differences in feedstock composition, but more investigation into different lignocellulosic

feedstocks are needed to determine the correlation between feedstock composition and the impact of nitrogen gas flow rate.

Overall, the findings from this study indicated that the pyrolysis conditions of biochar and ACs strongly affect CO₂ adsorption. Additionally, these findings suggest feedstock variety needs to be considered to optimize adsorption. These results demonstrate that biochar/ACs have potential as DAC sorbents, and these results can be a basis on future research on how to further optimize biochar/ACs for DAC applications.