CO_2 removal by applying the adsorption process to biochar from waste materials

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Introduction: The development and application of various methods for CO_2 capture have been investigated by researchers, aiming to advance technologies for mitigating both atmospheric CO_2 and emissions resulting from industrial combustion processes. Capturing CO_2 directly from fixed sources is critical to preventing or minimizing its release into the atmosphere, thereby enabling industries to meet the greenhouse gas reduction targets established by international agreements. Among these approaches, the utilization of non-fossil energy sources and the implementation of post-combustion capture techniques have demonstrated significant potential in addressing CO_2 emissions effectively. These capture methodologies involve various CO_2 separation processes, including absorption, membranes, chemical loop combustion, and adsorption (Bartosz Dziejarski et al., 2023). In order to achieve an efficient and economical carbon capture process, it is essential that the adsorbent has high efficiency, selectivity and stability. Solid adsorbents with these characteristics include zeolites, activated carbon, carbon nanotubes and silicon-based materials. Modifying the porosity and structure of these adsorbents can be done to optimize the selectivity of CO_2 in relation to other gases present in industrial streams (Sumida et al., 2012; Xiangzhou Yuan et al., 2022). Biochar, in particular, stands out as an efficient CO_2 adsorbent due to the presence of alkaline functional groups on its surface and its high microporous area (S. Gupta, 2018; Li, Y. et al., 2023). Research carried out by Lee et al. (2010), Ahmad et al. (2014), and Y. Ji et al. (2022) have highlighted the unique surface properties of biochar, which make it a highly promising material for capturing CO_2. According to Jarosław Serafin, et al., (2022) the reduction of CO_2 emissions into the atmosphere can be achieved by applying adsorption-based systems, such as carbon capture and storage, but they require careful selection of the adsorbent. Solid sorbents, particularly activated carbons (ACs), have a low cost, greater surface area, large pore volume, humidity stability, good chemical and thermal stability, recyclability, high mechanical resistance, and best of all great affinity with CO_2, and adjustable pore structure, highlighting the advantages of applying ACs. The CO_2 adsorption for the best activated carbon was 9.54, 5.17, 4.33 mmol/g for 25 °C and 40 °C, respectively. It has good process operability, material stability and the possibility of using different waste to produce new materials. In the work by Orlando F. C. et al., (2024), activated carbon from Amazonian biomass was used to capture CO_2 and methane. These agricultural biomasses, walnut shells and cupuaçu shells, were prepared to produce ultra microporous active carbons for the simultaneous capture of CO_2 and CH_4. The authors evaluated the CO_2 capture capacity of different activated carbon samples, their textural parameters and chemical composition. The authors evaluated CO_2 capture at 0 °C and 25 °C at 1 bar, which showed that the active carbons prepared had high absorption capacities. The CO_2 capture capacity value of 5.2 mmol/g was attributed to a combination of large surface area. Li et al. (2015) reported the use of activated carbon produced from rice husks, using KOH as an activating agent, to capture CO_2. In this condition, the capture capacity reached 2.1 mmol/g under a pressure of 1 bar and a temperature of 0 °C. Serafin et al. (2022) produced a low-cost carbon from Brazil nut shells, also activated with KOH, for CO_2 adsorption, achieving a capacity of 5.1 mmol/g under conditions of 0 °C and 1 bar. Huang et al. (2019) analyzed the adsorption of CO_2 at 25 °C and a pressure of 1 bar on charcoal derived from garlic peels, activated with KOH, and recorded a capacity of 4.4 mmol/g. Regarding the application of activated carbon and biochar in beds, we can mention the works of Ligero et al., (2023); C.Xu et al., (2024); A. Ansari (2024); A. Arifutzzaman et al., (2023); Cui Quan et al., (2023); F. Raganati et al., (2024) and Teixeira, P., et al., (2024). In the study by A. Ligero et al., (2023) the influence of the input CO_2 concentration, temperature and the mass of adsorbent in the bed was evaluated, concluding that the first two are of paramount importance. The best CO_2 absorption result was 78 mgg -1 with the highest CO_2 input (40%), the lowest temperature (15 ºC) and a moderate adsorbent load (1g).

The main objective of this study was to evaluate CO_2 capture using the adsorption method on activated carbon and biochar particles from coffee grounds waste and peanut shell pellets. The secondary objectives were to evaluate a packed bed, air and CO_2 flow variables in laboratory tests.

Materials and methods

Commercial activated charcoal (AC), peanut shell pellet charcoal (PSPC), coffee grounds biochar (CGB) and coffee grounds biochar treated with magnetic particles (CGB PM) were used as adsorbent materials. CGB and CGB PM were obtained by pyrolysis. The pyrolysis process was carried out in a continuous rotary kiln (FRO 1100) at a temperature of 600°C. The CGB PM was prepared using the chemical precipitation technique, $FeSO_4.7H2O$, and $FeCl_3$ (Zhantao Han, et al., 2015). The peanut shell pellets carbonized during the burning process at temperatures above 1000 C were collected, macerated and sieved. These products were inserted into a cylindrical bed with a mass of 14.23 g. The experimental apparatus shown in Figure 1 was used to evaluate the CO_2 capture process in a bed with adsorbents. CO_2 was measured by two optical infrared gas sensors located

before and after the bed, which have good selectivity, temperature compensation and digital output. CO_2 concentrations (ppm) were evaluated every 1 second. The flow rates of natural air and CO_2 were quantified using rotameters. Air flow rates of 10, 15, 17, 20 and 25 L/min were evaluated, while CO_2 flow rates were 0.3, 0.4, 0.6 and 0.8 L/min. Temperatures inside the bed remained between 20 and 25 ^oC. Glass fiber cotton was used to prevent the fine particles in the material from passing into the pipes. Figure 02 shows the CO_2 capture efficiency values for an air flow rate of 25 L/min.

Figure 01. Experimental CO_2 capture device.

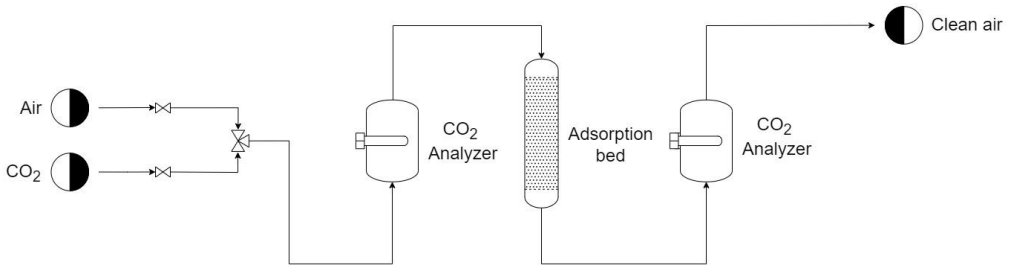
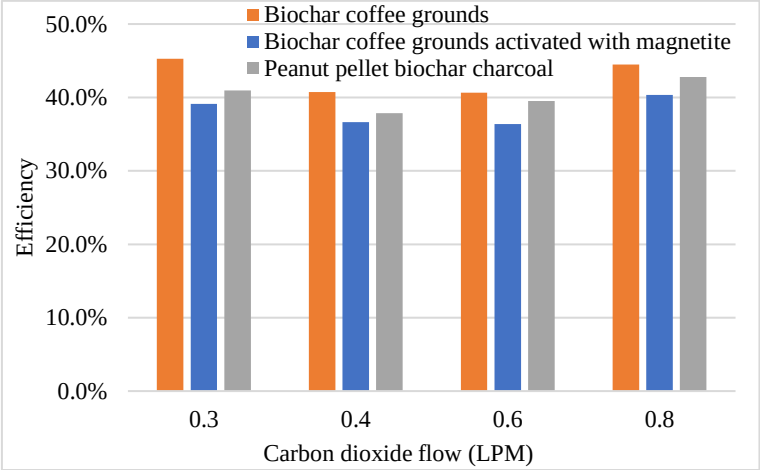


Figure 2: CO_2 captures efficiency in the bed for different adsorbents.



For all the tests evaluated, the CO_2 capture efficiencies were higher than 30%. For commercial activated carbon, the values were slightly higher in some tests, reaching 52% efficiency. Variations in air flow had no influence on efficiency, even though they altered the behavior of the bed. However, increasing the CO_2 flow rate showed a slight increase in capture efficiency. These efficiency results were very satisfactory, considering that the tests were carried out at low pressure and room temperature. All waste materials are suitable for large-scale use in industrial processes to minimize post-combustion CO_2 emissions. These efficiency values are in line with studies in literature. The efficiencies obtained by A. Ligero et al., (2023) varied around 40%. In the study by Serafin et al. (2021) they indicate that chemical activation using KOH produces activated carbon with high microporosity. They presented CO_2 capture efficiency results in the range of 12, 21.72 and 45 %. These values are due to an increase in surface area, with pore size distribution in the range between 0.60 nm and 1.15 nm.

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