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Potential of Activated Charcoal and Aniline-Modified Charcoal in Carbon Dioxide Capture

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ABSTRACT

This study investigated the CO_2 adsorption capacity of activated charcoal and aniline-modified charcoal. Commercial activated charcoal was used while the aniline-modified charcoal was prepared using wet impregnation method. The results of the CO_2 capture experiment showed that both adsorbents exhibited varying degrees of CO_2 adsorption, with aniline-modified charcoal demonstrating enhanced adsorption capacity reporting maximum adsorption capacity of 1530 ppm corresponding to 45% absorption rate at 420 seconds. However, the activated charcoal demonstrated maximum adsorption capacity of 950 ppm (32.20% absorption rate) at 420 seconds. The findings highlighted the potential applications of these adsorbents in CO_2 capture and storage.

Keywords: Activated charcoal, aniline-modified charcoal, CO_2 adsorption, climate change mitigation.

INTRODUCTION

The escalating levels of atmospheric CO_2, primarily driven by fossil fuel combustion and industrial activities, pose a significant threat to the global climate. According to recent estimates, global fuel combustion released approximately 32.8 billion tons of CO_2 [1]. The increased use of personal vehicles, driven by overpopulation, further exacerbates the rise in CO_2 levels. The 2015 UN Climate Change Conference underscored the urgent need for global action to prevent severe climate change by limiting global warming below 2 °C and striving to keep it below 1.5 °C [2]. In line with this goal, the Intergovernmental Panel on Climate Change (IPCC) emphasizes the importance of reducing CO_2 emissions to keep atmospheric concentrations below 450 ppm by the end of 2100 and prevent irreversible climate change.

Various methods have been developed for CO_2 removal from gas streams, including adsorption, absorption, cryogenics, and membranes [3]. Among these, adsorption technology has emerged as a promising approach due to its cost-effectiveness and efficiency. Recent advancements in nano-materials, particularly amine-modified nano-materials, have shown great potential for enhancing CO_2 adsorption capacity and selectivity. These nano-materials exhibit low energy consumption, chemical stability, and reversible nature, making them an attractive solution for CO_2 chemical adsorption. Amine-modified nanomaterials with porous structures, large surface areas, and abundant gas diffusion channels have proven effective for CO_2 adsorption. For instance, nanosilica, carbon nanotubes, nano cellulose, metal-organic frameworks (MOFs), and porous alumina have been explored as support materials for amine groups [4]. MOFs, in particular, have garnered attention due to their well-defined adsorptive sites, adjustable pore sizes, and functionalities.

Recent studies have demonstrated the potential of amine-modified MOFs for CO_2 capture, showcasing high adsorption selectivity and capacity [5]. Furthermore, ionic liquids (ILs) have emerged as a promising option for CO_2 adsorption due to their structure tunability, CO_2 affinity, and low volatility. Nanomaterials with high levels of amine-modified ILs have shown potential for CO_2 chemisorption, offering high sorption capacity and rapid reversibility [2]. The development of cellulose-supported solid ionic liquids (SoILs) has also been explores, demonstrating effective and low-cost sorbents for CO_2 capture [6].

This study focuses on enhancing the effectiveness of adsorption technology for CO_2 capture. The research investigates the potential of amine-modified materials (aniline-modified charcoal) for CO_2 adsorption. This research aims to contribute to the development of efficient and sustainable CO_2 capture technologies for climate change mitigation.

MATERIALS AND METHODS

Materials

Analytical grades 99.9% Activated charcoal (Sigma-Aldrich), 99.99% Carbon dioxide gas, ethanol (99.8%, Sigma Aldrich), and aniline (99.5%, Sigma Aldrich) were used in this research work.

Sample Preparation

The aniline-modified charcoal adsorbent material was prepared by a wet impregnation method as reported elsewhere [7]. To start, 6.7 g of the activated charcoal (40% of the adsorbent) was weighed and added to a crucible. Then, 10 g of aniline (60% of the adsorbent) was slowly added while stirring. Next, 77.38 g of ethanol (solvent) was gently added, and the mixture was stirred until uniform. The mixture was placed in an oven, where the ethanol was evaporated at 80 ^{o}C for 4 hours. After drying, the sample was crushed into a power, resulting in the final aniline-activated charcoal adsorbent material. Equation (1) represents the mass fraction of amine (aniline) in the adsorbent material.

$$Mass\ fraction\ (\%)\ Aniline = \frac{M.Aniline}{M.Aniline + M.AC} \times 100\% \qquad (1)$$

$M._{Aniline}$ = Mass of Aniline

M_{AC} = Mass of activated charcoal

Adsorption Process

The adsorption performance of each adsorbent (activated charcoal and aniline-modified charcoal) was studied at 35 ^{o}C, under atmospheric pressure in a continuous flow fixed bed reactor with an adsorption bed of 18 mm (inner diameter) and 10 cm length as presented in Figure 1**.** The reactor was placed horizontally on a stand. The introduction of CO_2 gas into the reactor was monitored and controlled by calibrated mass flow meter. Before the adsorption performance test, 6.5 g of adsorbent (either activated charcoal or aniline-modified charcoal) was sandwiched between two layers of glass wool in the adsorption bed and both ends of the adsorption bed was covered with rubber cocks with a holes at the centers (for the inlet and outlet of CO_2 gas). The CO_2 gas outlet pipe from the reactor bed was connected with container with 12 cm by 12 cm dimension and in this container a digital CO_2 monitoring device (NZ-2CO9) was placed. Afterwards, CO_2 gas was introduced into the reactor at a low rate of 40 mL/min, under atmospheric pressure as reported elsewhere [7]. Readings were recorded after every 30 seconds and each experiment was conducted in duplicate. The adsorption performance that is CO_2 adsorbed and %CO_2 adsorbed was calculated as follows using equation (2) and (3) respectively.

$$C_oCO_{2\ ppm} = (C_{control}CO_2 - C_1CO_2)\ ppm \qquad (2)$$

$$\% CO_{2ad} = \frac{C_oCO_2}{C_{control}CO_2} \quad (3)$$

Where:

$C_{control}CO_2$ = Concentration of CO_2 in the container without adsorbent material in the adsorption bed

C_oCO_2 = Concentration of CO_2 Adsorbed (ppm)

C_1CO_2 = Concentration of CO_2 available in the container after adsorption (ppm)

$\% CO_{2ad}$ = % CO_2 adsorbed

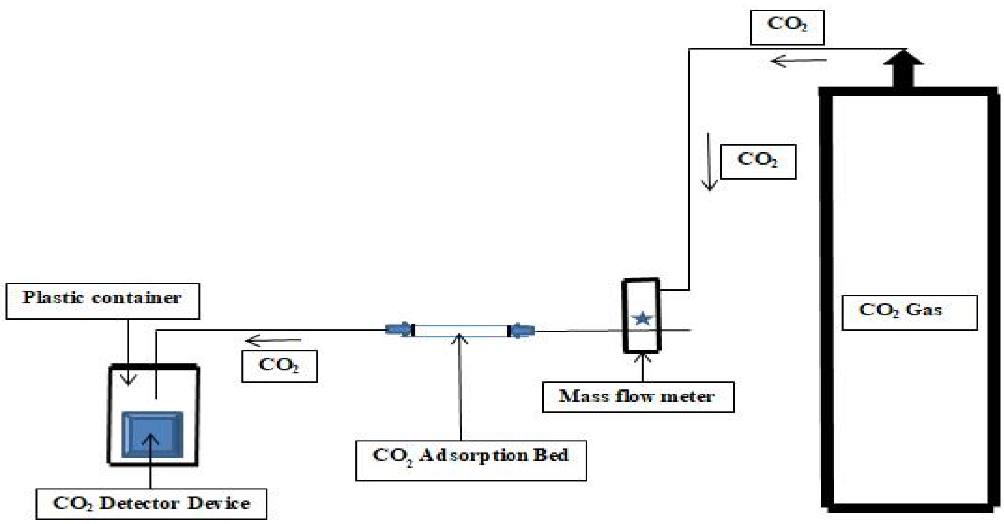

Figure 1: Schematic Diagram for the CO_2 Adsorption Process Set-Up

RESULTS AND DISCUSSION

Table 1 presents the results of the control experiment for CO_2 adsorption without an adsorbent. The data indicates that the CO_2 concentration remains steady at 414 ppm for the first 270 seconds. Beyond this point, the CO_2 concentration begins to rise, reaching to 1017 ppm at 300 seconds and steadily increasing to 5020 ppm by 600 seconds. As expected, without an adsorbent, the CO_2 concentration is unaffected by adsorption, resulting in 0% CO_2 adsorbed throughout the experiment.

Table 1: Results of the Control Experiment for CO_2 Adsorption without Adsorbent

M_{Ad} (g)	$_{mL}CO_2$	tCO_2 (Sec.)	$C_{control}CO_2$ (ppm)	C_oCO_2 (ppm)	% CO_{2ad}
0	0	0	414	0	0
0	20	30	414	0	0
0	40	60	414	0	0
0	60	90	414	0	0
0	80	120	414	0	0
0	100	150	414	0	0
0	120	180	414	0	0
0	140	210	414	0	0
0	160	240	414	0	0
0	180	270	414	0	0
0	200	300	1017	0	0
0	220	330	1217	0	0
0	240	360	1720	0	0
0	260	390	2112	0	0
0	280	420	2950	0	0
0	300	450	3530	0	0
0	320	480	4150	0	0
0	340	510	4360	0	0
0	360	540	4550	0	0
0	380	570	4800	0	0
0	400	600	5020	0	0

$C_{control}CO_2$ = Concentration of CO_2 in the container without adsorbent material

C_oCO_2 = Concentration of CO_2 Adsorbed (ppm)

% CO_{2ad} = % CO_2 adsorbed

M_{Ad} = Mass of adsorbent

tCO_2 = CO_2 Released time

$_{mL}CO_2$ = CO_2 released (mL)

The results presented in Table 2 reveal the CO_2 adsorption capacity of activated charcoal. The data shows constant CO_2 concentration for the first 270 seconds, the CO_2 concentration remains constant at 414 ppm and this indicates there no adsorption during 270 seconds. The CO_2 adsorption was observed at 300 seconds, with the amount of CO_2 adsorbed increasing with time. The maximum CO_2 adsorption capacity is observed at 420 seconds, with 950 ppm of CO_2 adsorbed, corresponding to a 32.20% adsorption rate which is in agreement with the research carried out by [8] that reported a CO_2 adsorption capacity of 26.7% on activated carbon. At time above 420 seconds, the adsorption rate decreases, and the amount of CO_2 adsorbed decreases, indicating saturation of the adsorbent material.

Table 2: Results of the CO_2 Adsorption on Activated Charcoal

M_{Ad} (g)	$_{mL}CO_2$	tCO_2 (Sec.)	$C_{control}CO_2$ (ppm)	C_1CO_2 (ppm)	C_oCO_2 (ppm)	% CO_2ad
6.5	0	0	414	414	0	0
6.5	20	30	414	414	0	0
6.5	40	60	414	414	0	0
6.5	60	90	414	414	0	0
6.5	80	120	414	414	0	0
6.5	100	150	414	414	0	0
6.5	120	180	414	414	0	0
6.5	140	210	414	414	0	0
6.5	160	240	414	414	0	0
6.5	180	270	414	414	0	0
6.5	200	300	1017	752	265	26.06
6.5	220	330	1217	900	317	26.05
6.5	240	360	1720	1200	520	30.23
6.5	260	390	2110	1460	650	30.78
6.5	280	420	2950	2000	950	32.20
6.5	300	450	3490	2550	940	26.93
6.5	320	480	4150	3350	800	19.28
6.5	340	510	4360	4300	60	1.38
6.5	360	540	4550	4450	100	2.20
6.5	380	570	4800	4600	200	4.17
6.5	400	600	5020	4740	280	5.58

C_1CO_2 = Concentration of CO_2 in the container after application of adsorbent (ppm)

The results presented in Table 3 demonstrate the CO_2 adsorption capacity of aniline-modified charcoal. Again, the data shows constant CO_2 concentrations of 414 ppm for the first 270 seconds. The aniline-modified charcoal shows a similar adsorption trend to activated charcoal (Table 2), but with slightly higher adsorption capacities at certain times. At 300 seconds the amount of CO_2 adsorbed was 367 ppm which translated to 36.09% CO_2 adsorbed and this is inconformity with findings elsewhere [9] that reported a CO_2 adsorption capacity of 32.5% on modified activated carbon.

The maximum CO_2 adsorption capacity is observed at 450 seconds, with 1530 ppm of CO_2 adsorbed, corresponding to a 45% adsorption rate. At time above 450 seconds, the adsorption rate decreases, and the amount of CO_2 adsorbed decreases, indicating saturation of the adsorbent. The findings of this study are consistent with previous research on CO_2 adsorption using activated charcoal and modified activated charcoal. For example, a study by Shen *et al*. [10] reported that modified activated charcoal exhibited enhanced CO_2 adsorption capacity compared to unmodified activated charcoal. Another study by Zhang *et al.* [11] demonstrated the potential of activated charcoal for CO_2 capture and storage.

Table 3: Results of the CO_2 Adsorption on Aniline-Modified Charcoal Adsorbent

M_{ad} (g)	mL CO_2 released	Time/s	Conc. of CO_2 in the container (ppm) without adsorbent	Conc. of CO_2 in the container (ppm)	Conc. of CO_2 Adsorbed (ppm)	% CO_2 adsorbed
6.5	0	0	414	414	0	0
6.5	20	30	414	414	0	0
6.5	40	60	414	414	0	0
6.5	60	90	414	414	0	0
6.5	80	120	414	414	0	0
6.5	100	150	414	414	0	0
6.5	120	180	414	414	0	0
6.5	140	210	414	414	0	0
6.5	160	240	414	414	0	0
6.5	180	270	414	414	0	0
6.5	200	300	1017	650	367	36.09
6.5	220	330	1217	760	457	37.5
6.5	240	360	1720	1000	720	41.86

6.5	260	390	2112	1212	900	42.61
6.5	280	420	2950	1650	1300	44.07
6.5	300	450	3400	1870	1530	45.00
6.5	320	480	4150	2770	1380	33.25
6.5	340	510	4360	3600	760	17.43
6.5	360	540	4550	3740	810	17.80
6.5	380	570	4800	3950	850	17.71
6.5	400	600	5020	4140	880	17.53

CONCLUSION

This study revealed the potential of activated charcoal and aniline-activated charcoal for CO_2 adsorption particularly in continuous flow system. The findings highlighted the importance of modifying activated charcoal to enhance its CO_2 adsorption capacity. Activated carbon reported maximum sorption capacity of 950 ppm (32.20% absorption rate) at 420 seconds while the aniline-activated charcoal reveals maximum sorption capacity of 1530 ppm (45%) at 450 seconds. The results suggest that activated charcoal and aniline-activated charcoal have potential applications in CO_2 capture and storage, particularly in industrial settings where CO_2 concentrations are high. However, further research is needed to optimize the CO_2 adsorption process and develop efficient methods for CO_2 capture and storage.

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