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Performance of Green Coconut Coir as the Potential Adsorbent for Sequestration of Carbon Dioxide in Natural Gas

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Abstract: *In Malaysia, abundant agricultural wastes are generated yearly. Therefore it is beneficial to discover new ways to utilize the wastes and employ the carbon source in different industries. There have only been a few studies that discuss on the potential applications of agricultural waste such as coconut coir or fibre as carbon sequesters through usage of adsorbents. Adsorbents are produced through many heat treatments such as torrefaction, combustion and pyrolysis. Green coconut coir being rich with the content of cellulose and lignin, which are potential pollutant adsorber, is chosen for production of adsorbents in this work. The adsorbents are used in the adsorption process to determine the adsorption efficiency of green coconut coir in adsorbing CO_2 gas. CO_2 contaminates the natural gas by affecting its heating value which reduces the quality of the natural gas. Therefore, the adsorption of CO_2 gas will reduce the acid gas presence in natural gas hence it will improve the natural gas purification process. The moisture was removed from the coir by drying at 110˚C for 6 hours. Next, the coir was torrefied at five different temperatures which are 200˚C, 250˚C, 300˚C, 350˚C, and 400˚C with different dwelling times. Through torrefaction process, the char content of each sample was able to be determined. The highest adsorption capacity obtained was 62.47mg/g at 400˚C with dwelling time of 90min. From this study, it was discovered that green coconut coir has a high potential as adsorbents for CO_2 sequestration considering its inexpensive cost and availability.*

Keywords: *Green Coconut Coir, Potential Adsorbent, Sequestration of Carbon Dioxide, Natural Gas*

1. Introduction

At present, the abundance of the agro-wastes in Malaysia poses serious threats to both environment and society. Though agro-wastes are not classified as hazardous materials, but still they constitute a huge volume of total waste materials (Kuan and Liong, 2008). Besides, it is estimated that five million tons of agro-wastes have been produced annually in Malaysia (Pang et al., 2006). These materials are highly porous carbons, which exhibit several advantages as CO2 adsorbents which are low cost, high adsorption capacity, easy regeneration and no degradation by moisture (Aiméet al., 2013). Common practice of biomass disposal is often achieved by using two main methods – dumping in the landfill and open burning which will worsen the existing air pollution and results in a non-aesthetic view (Nor et al., 2012). This research is on the performance of CO2 sequestration in natural gas using green coconut coir as potential adsorbent. Coconut fibre (Cocosnucifera) is extracted from the outer shell of a coconut (Majid A., 2010). Examples of agricultural wastes used as adsorbent for sequestration of CO2 are coconut shells, peanut shells, corn cob, palm kernel, and what is being proposed in this paper is green coconut coir/fibre. Coconut coir is chosen as an option for adsorbent is mainly because of its availability. It can be found in an abundant amount, especially at beaches or tourism sites. The coconut coir will be dried at 110 ˚C, and then put under torrefaction process. Next, the biochar will be crushed and is ready to test

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for its capability in adsorbing CO2. Also, through analysis, the parameters that affect the adsorption capacity of CO2 will be determined for example temperature and pressure.

At higher temperature, the average time spent by a molecule on the surface (residence time) is lower (Anonymous O, 2014). The extent of uptake of an adsorbent reduces with increasing temperature, so warming of the system is likely to lead to reduced uptake. Adsorption is of course a process which evolves heat. It should also be borne in mind that the total amount of gas stored within a carbon or other adsorbent under pressure is not simply the amount adsorbed in the micropores. This ignores the contribution made by the natural gas in the voids and larger pores where it is stored (Judd et al., 2014). Low lignin content gives rise to easy accessibility of adsorbate to active sites (Rawangkulet al., 2010). The composition of biomass fuels includes cellulose and hemicelluloses; they are highly oxygenated (Malatji P., 2009). This means that higher content of lignin and cellulose support in the increment of adsorption capacity of the biochar. The rate of adsorption increase as the average pore size increases (Mangunet al., 1997).

This research is focus on investigation of adsorption efficiency at various torrefaction temperatures for sequestration of CO2 contained in natural gas.

2. Materials and Methods

2.1 Materials and Chemicals

Table 2.1 explained on the materials and chemicals which are involved in the project. Each material or chemical in the list is followed by a description of its significance in the project.

TABLE II.1*:* List of Materials & Chemicals

Material/Chemical	Description
Coconut Coir	To be torrefied into char (adsorbent) at different temperatures with different dwelling times in order to study on its adsorption efficiency.
Cotton Wool	To be used at the adsorption column during the adsorption test to prevent the char samples from being pushed out from the column and into the pipelines.
Tapes	Used at the Gas Adsorption Unit to reduce and ultimately prevent any possible leakages.
Plasticine	
Plastic Cups	To store the prepared char samples for any further use.
Carbon Dioxide, CO_2	To be used as a variable (adsorbate) in determining adsorption capacity of each type of char (adsorbent) sample.

2.2 Equipments

Table 2.2 described on the equipments or machineries used to make it possible to proceed with the experimentation process of the project. Each respective equipments in the list has been explained on its purpose of usage as well as its model.

TABLE II.2: List of Equipments

Equipment	Model	Description
Drying Oven	ULM 500	A medium for drying. Coconut fibre will be dried at 110˚C for about 6 hours prior to torrefaction before proceding with the adsorption test.
Muffle Furnace	ELF 11/14B	A medium for combustion (torrefaction). Dried samples will be torrefied at a range of 200˚C to 400˚C, with dwelling times of 60min, 90min, and 120min each.
Gas Adsorption Unit	SOLTEQ BP 200	Acts as a medium of experimentation. To determine adsorption capacity of char samples prepared.
Glassware	BOECO Boro 3.3, IWAKI TE-32	Instruments used for the preparation of the samples before the adsorption test.
Blender	MX 900m	A medium used to grind the char samples into smaller pieces or powder.
Flour Sieve	-	To filter fine char samples apart from the larger samples.

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2.3 Method of Preparation

About 10 young (green) coconuts were obtained from a local fruit stand at TabohNaning, Melaka. Approximately 1.5 kg worth of coconut coir (fibre) was oven-dried. The coir was put onto several soda wash glasses and into the Drying Oven (Model: ULM 500), at 110˚C for 6 hours. Upon completing the drying of the coconut coir samples, the dried samples were torrefied, using a Muffle Furnace (Model: ELF 11/14B), at five distinct torrefaction temperatures (200˚C, 250˚C, 300˚C, 350˚C, 400˚C) with each torrefaction temperature experimented with dwelling times of 60min, 90min, and 120min to acquire char samples (adsorbent) with different adsorption capacities. Next, the char samples obtained were blended and sieved into smaller pieces to be used later in the Gas Adsorption Unit (Model: SOLTEQ BP 200). The prepared samples were then stored in a suitable container for further use. The mass of green coconut coir before drying and after drying were used to calculate the total moisture content. Whereas, the mass of dried green coconut coir and torrefied green coconut coir were used to compute the char content.

2.4 Adsorption Test

About 7g of char sample was placed in the Adsorption Column (Cotton Wool is fitted at the top and bottom of the column to prevent sample from being pushed into the pipelines). Valve 1 (V1) and Valve 2 (V2) were opened. The CO_2 gas was allowed to flow through the entire system until the Pressure Gauge (PG) has indicated 2 bars. Next, V1 was closed, and the system was left to adapt for about 5 minutes. Later, the prepared samples were put through the Gas Adsorption Unit (Model: SOLTEQ BP 200) in order to determine each sample's adsorption efficiency. The samples were tested at ambient temperature (≈32˚C), pressure (2 bars), and Batch Process. Later, the PG was observed and the pressure drop readings were recorded for intervals of 5 seconds. The pressure drop values obtained were then used to calculate the adsorption capacities of biochar at different conditions. Should the pressure reading falls at a fast pace, means that there are possible leakages present at the system and corrective measures have to be taken to fix the problem before proceeding with the Adsorption Test. *Figure 2.1* showed the set-up of the Gas Adsorption Unit where the leakage and adsorption tests will be carried in as described.

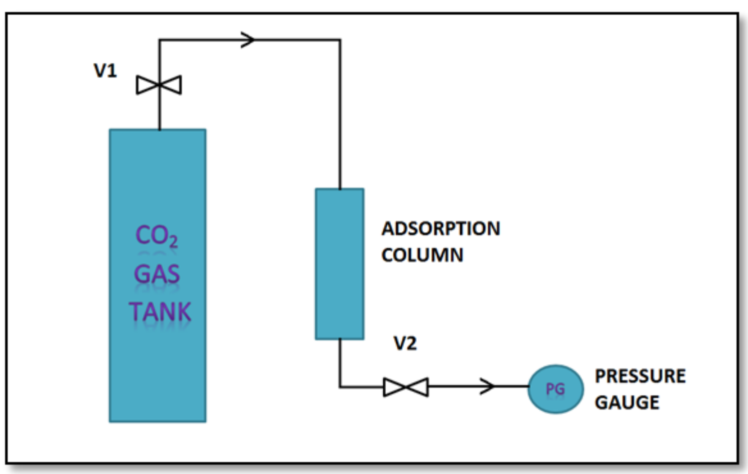

Fig. 2.1: Gas Adsorption Unit

2.5 Analyses

2.5.1 Moisture and Char Content

Equation 2.1 shows the formulation used to compute the value of moisture content. mwet represents the mass before drying, whereas mdry represents the mass after drying.

$$\text{Moisture Content (\%)} = \frac{m_{wet} - m_{dry}}{m_{wet}} \times 100\% \tag{2.1}$$

Equation 2.2 shows the formula for calculating the value of char content. mfinal represents the mass after torrefaction, whereas minitial represents the mass before torrefaction.

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$$\text{Char Content (\%)} = \frac{m_{final}}{m_{initial}} \times 100\% \quad (2.2)$$

2.5.2 Adsorption Capacity

Equation 2.3 shows the formulation used to compute the value of adsorption capacity. Co indicates the initial concentration of the biochar sample, Ct indicates the concentration on the time, W represents the weight of the biochar sample, and V represents the volume supplied by the container.

$$\text{Adsorption Capacity}, q_t = \frac{C_o - C_t}{W} V \quad (2.3)$$

3 Results and Discussion

3.1 Moisture Content

Table 3.1 shows the values for mass of green coconut coir before and after the drying process. The mass of green coconut coir before being dried in the drying oven is 10140.59g whereas the mass of green coconut coir after the drying process is 1200.97g. These values were used to calculate the total moisture content removed from the potential adsorbent after being dried. The total moisture content removed from the green coconut coir was calculated using Equation 2.1 in Section 2.5.1. It was discovered that a total of 8939.62g of mass was reduced by the end of the drying process. It can be observed that the value of mass has decreased by the end of the process. The mass reductionproves that the moisture was removed from the green coconut coir. Hence, the percentage of total moisture removed from the green coconut coir after drying was able to be obtained which was 88.16%.

TABLE III.1: Results for Moisture Content

Variables	Results
Mass of Green Coconut Coir Before Drying, m_{wet} (g)	10140.59
Mass of Green Coconut Coir After Drying, m_{dry} (g)	1200.97
Moisture Content (%)	88.16

3.2 Char Content

Table 3.2 shows the values for mass of biochar before torrefaction, after torrefaction, as well as the char content of the green coconut coir after torrefaction. The term 'CC-200-60' as shown in Table 3.2 represents the abbreviation for the conditions of the respective sample of 'Coconut Coir-200˚C-60min' which denotes 'Sample-Torrefaction Temperature-Dwelling Time'. It can be observed that the mass of biochar after torrefaction decreases with increasing temperature and increasing dwelling time. This is probably due to conversion of green coconut coir into ash as it dwells longer or with higher temperature within the muffle furnace. The values of mass before and after torrefaction were used to calculate the char content present after the torrefaction process of each sample at their respective conditions. The char content of the biochar after torrefaction was calculated using Equation 2.2 in Section 2.5.2. It can be observed from Figure 3.1 that biochar at 200˚C has the highest percentage of char content whereas the biochar of 400˚C has the lowest percentage of char content. So, it can be seen that the values for char content generally decreases with higher temperature and dwelling time. Hence, the longer the sample dwells within furnace with higher temperature, the more likely the sample will turn to ash rather than biochar.

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TABLE III.2*:* Results for Char Content

Sample	Mass of Biochar Before Torrefaction (g)	Mass of Biochar After Torrefaction (g)	Char Content (%)
CC-200-60	50.00	36.39	72.78
CC-200-90	50.25	38.11	75.84
CC-200-120	50.03	36.55	73.06
CC-250-60	50.02	13.78	27.55
CC-250-90	50.04	24.58	49.12
CC-250-120	50.02	30.75	61.48
CC-300-60	100.01	43.57	43.57
CC-300-90	100.06	37.74	37.72
CC-300-120	100.01	34.07	34.07
CC-350-60	100.13	31.63	31.59
CC-350-90	100.05	29.24	29.23
CC-350-120	100.05	13.84	13.83
CC-400-60	100.13	22.71	22.68
CC-400-90	100.1	10.95	10.94
CC-400-120	100.07	9.05	9.04

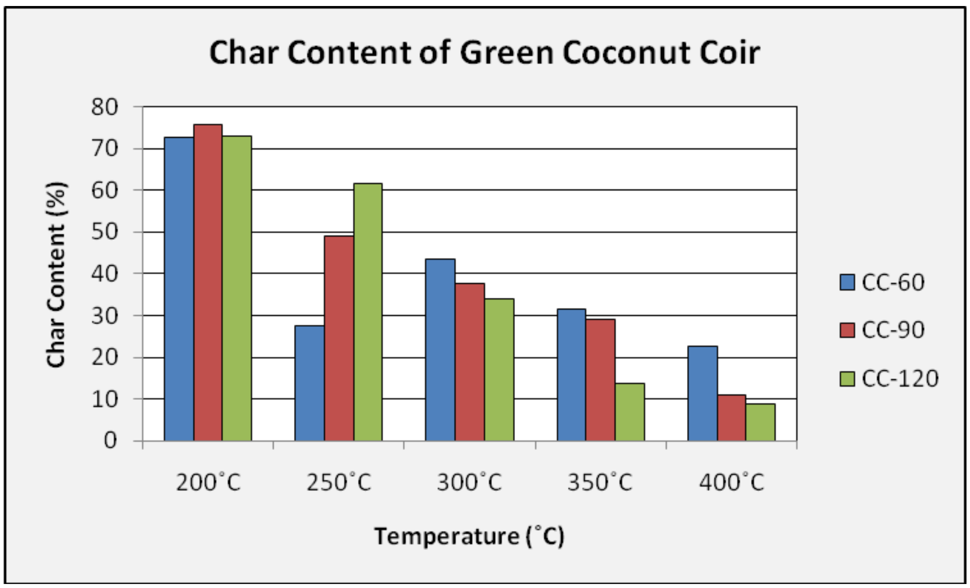

Fig. 3.1: Char Content of Biochar against Torrefaction Temperature

3.2 Adsorption Capacity

Table 3.3 showed the values for adsorption capacity obtained through calculations using Equation 2.3 in Section 2.5.3. The first and the last pressure drop values of each respective sample were used to compute the values of adsorption capacity. It can be observed that the values for adsorption capacity increases in an overall view but gradually decreases as it reaches the torrefaction temperature of 350˚C and above. For instance the adsorption capacity for biochar at dwelling time of 120min, it can be observed that it showed an increasing trend from temperature of 200˚C until 350˚C but decreases as it enters the temperature of 400˚C. Not just that, the values of adsorption capacity shown in Table 3.3 were used to generate two graphs which are Figure 3.2: Adsorption Capacity against Dwelling Time and Figure 3.3: Adsorption Capacity against Torrefaction Temperature, which were used to do comparative studies on the values of adsorption capacity between different torrefaction temperatures and dwelling times. It can be observed from Figure 3.2 that among the three dwelling

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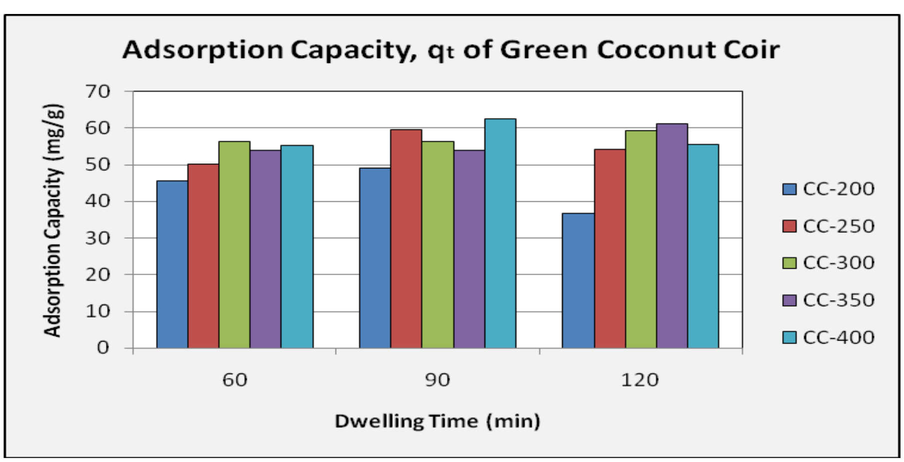
times, the time that showed the most optimum adsorption capacity yet stable is of 'CC-90' at 400˚C and 'CC-120' at 350˚C. These two values showed the most potential as adsorbent for CO_2 sequestration. But as seen in *Table 3.3*, the values of adsorption capacity at 400˚C with time of 90min decreases, this means that the biochar's crucial composition is more prone to decomposition compared to that of biochar at 350˚C with time of 120min. Hence, biochar at 350˚C with time of 120min is the ideal choice. Next, it can be observed from *Figure 3.3* that the optimum torrefaction temperature which presented the most stable adsorption capacity values is of 'CC-300' for all three dwelling times. 'CC-300-60' with adsorption capacity of 56.37mg/g, followed by 'CC-300-90' with adsorption capacity of 56.37mg/g, and at 'CC-300-120' with adsorption capacity of 59.24mg/g. Hence, it was proven from the results obtained that the values of adsorption capacity for 'CC-300' do no deviate too much from one another whereas the values of adsorption capacity for other conditions has high deviations between each other. Thus, it can be deduced that the optimum conditions for adsorption capacity of green coconut coir biochar are at 'CC-300-120' and 'CC-350-120'. Lignin and cellulose content highly contribute to the adsorption efficiency due to their role as potential pollutant (CO_2) adsorbent. Higher micropore size (Larger surface area) means higher adsorption capacity. Being torrefied at a too high temperature or torrefied for too long could cause the adsorption capacity of the biochar sample to decrease. The reason for this is if the condition of the sample exceeds its optimum condition, the composition (lignin and cellulose), micropore size and surface area of the biochar will begin to deteriorate and will directly affect the adsorption capacity.

TABLE III.3*:* Results for Adsorption Capacity

Sample	Adsorption Capacity, q_t ($mg_{CO2}/g_{biochar}$)
CC-200-60	45.598
CC-200-90	49.19
CC-200-120	36.62
CC-250-60	50.27
CC-250-90	59.6
CC-250-120	54.21
CC-300-60	56.37
CC-300-90	56.37
CC-300-120	59.24
CC-350-60	53.86
CC-350-90	53.86
CC-350-120	61.04
CC-400-60	55.29
CC-400-90	62.47
CC-400-120	55.65

Fig. 3.2: Adsorption Capacity against Dwelling Time



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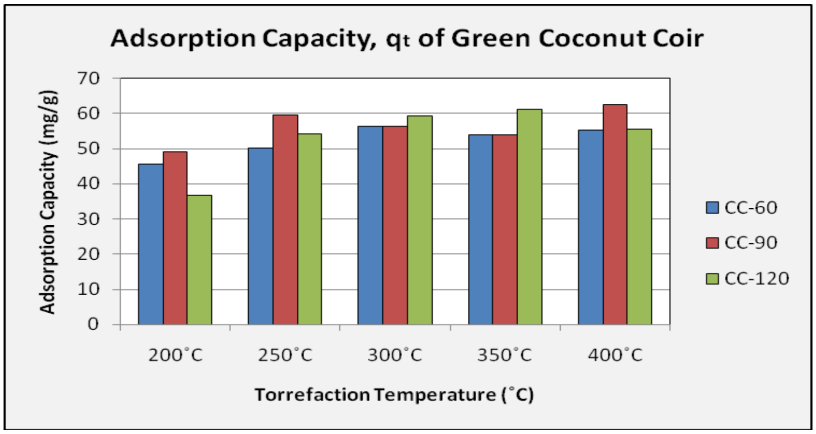

Fig. 3.3: Adsorption Capacity against Torrefaction Temperature

4 Conclusion

Based on the results, it can be deduced that the optimum conditions for adsorption capacity of green coconut coir biochar are at 'CC-300-120' and 'CC-350-120'. Based on the findings, temperature by which the samples were torrefied as well as the time the sample dwells during torrefaction significantly affect the adsorption capacity. This project experimented and researched on the optimum temperature as well as the dwelling time which gives the most in terms of CO_2 adsorption efficiency and discovered that 'CC-300-120' and 'CC-350-120' have the highest potential as adsorbent for the sequestration of CO_2.

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