Activated Carbon for Carbon Dioxide Gas Adsorbent

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Abstract. Carbon dioxide from the biogas resulted in vinasse fermentation should be treated. One of the methods that could reduce carbon dioxide was the adsorption process. A chemical and physical process could modify the characteristic of carbon and obtain activated carbon as an adsorbent. Chemical activation using H2SO4 ranged from 5% to 30%, and physical activation using pyrolysis at 400oC for 3 hours. The adsorption process was done by inserting 98.68% synthetic CO2 range from 0.002 to 0.0058 L/min from the bottom of the adsorption column with 5 cm in diameter and 30 cm in height. Chemical activation with 25% H2SO4 achieved the best result. Characteristics of activated carbon were analyzed using proximate and BET analysis, where the ash content was 3.93%, fixed carbon 80.015, the surface area was 5992.65 m2/gr with a total pore volume of 39.4620 cc/gr, and pore radius average was 2.6072 Å. The value of CO2 adsorbed was 99.939% at a gas rate of 0.0022 L/min.

Keywords. Adsorbent, Carbon, Carbon Dioxide, Sulfuric Acid

1 Introduction

Wastewater treatment of vinasse from the alcohol fermentation industry was necessary to reduce the pollutant. Vinasse could be treated and produced biogas using activated sludge resulted from cow dung treatment with a concentration of methane (CH_4) was 43.89 to 58.06% [1]. Those methane concentration needed to be processed to remove the carbon dioxide (CO_2) from the biogas and enhance the methane up to 60%. The CO_2 removal procedure could be using an adsorption process. Carbon as one porous material could be chosen as gas adsorbent. It had higher inner surface area than the outer surface [2].

Activated carbon has a porosity shrouded by carbon (marsh 2006). It could be defined as amorphous carbon with high porosity and surface area of about 500-2,000 m2/gr [3]. Due to the porosity, activated carbon is widely used in gas adsorption applications [4].

Lignocellulose material could be processed to produce activated carbon. Several biomasses, such as coconut shell, are already used to produce them [5]. Lignin-based activated carbon, generally activated under the carbonation process at 600 to 800°C, needs more energy than cellulose-based activated carbon, which can be activated at 450°C. Besides the physical method, cellulose-based activated carbon was activated by the chemical method.

Carbon activation could be done in physical and chemical processes. The physical process using pyrolysis aims to increase the physical characteristic of the adsorbent using high temperature. The unstable bond of the adsorbent compound would be broken and form a radical compound. The stabilization process of that compound would release volatile compounds [6]. Chemical activation impregnates the carbon with a chemical compound and heat.

The chemical activation process would change the carbon structure and pores [7]. Using acid as an activator made the carbon surface became acid, which led to the formation of functional oxygen group and gave hydrophilic group to the activated group. Sulfuric acid could be formed in some functional groups, like sulfide, disulfide, sulfonic acid, sulfoxide, and sulfone [8]. The sulfuric base activator caused a decrease in total volume pore and specific outer surface [9]. The increase of H_2SO_4 concentration leads to the higher potency of the functional group.

Activated carbon with the H_2SO_4 as activator had functional groups, such as hydroxyl (O-H), carboxyl (COOH), and sulfoxide (S-O) that come from the sulfonate group (SO_3H). The formation of the sulfuric functional group from carbonization produces several carbon structures that did not have functional groups.

Gas adsorption ability is influenced by adsorbent texture. That procedure needed adsorbent with micro size pore (d < 20 Å) due to the gas molecule size being less than 4 Å [10]. The gas adsorption process is also influenced by molecule's interaction, van der Waals force, which is related to the polarity of the adsorbent molecule. Higher adsorbent surface area, the van der Waals interaction would occur more often, which led to higher gas adsorption. If the molecule size is

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proportional to the adsorbent pore size, the gas would adsorb into the adsorbent. This procedure called steric mechanism.

The focus of this study was to investigate the activity of activated carbon in CO_2 adsorption. Characteristics of the adsorbent were evaluated using proximate and BET analysis, while the CO_2 adsorbed was detected by gas chromatography.

2 Experimental

The application of carbon for CO_2 adsorption showed in Fig. 1. The diameter of the adsorption column was 5 cm while the height was 30 cm. Carbon as an adsorbent was placed in the column at 28 cm in depth. It was conditioned on size -50/+70 mesh and activated chemically using sulfuric acid ranged from 5 to 30%. Carbon was also activated physically with the pyrolysis process on 400°C for 3 hours. The adsorption process was run with 98.86% synthetic CO_2 flowing into the column from the bottom side. The CO_2 flow rate differed from 0.0022 L/min to 0.0058 L/min. The outlet gas was collected in a gas bag to analyze CO_2 concentration.

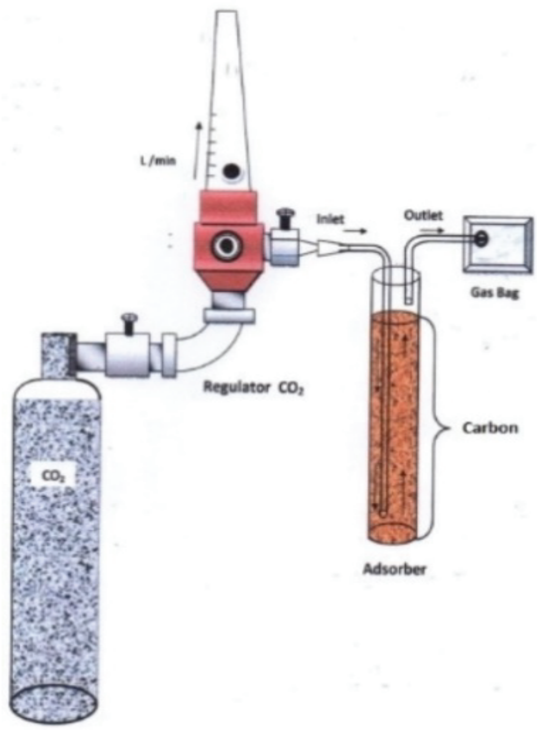

Fig. 1. Schematic diagram of CO_2 adsorption using activated carbon.

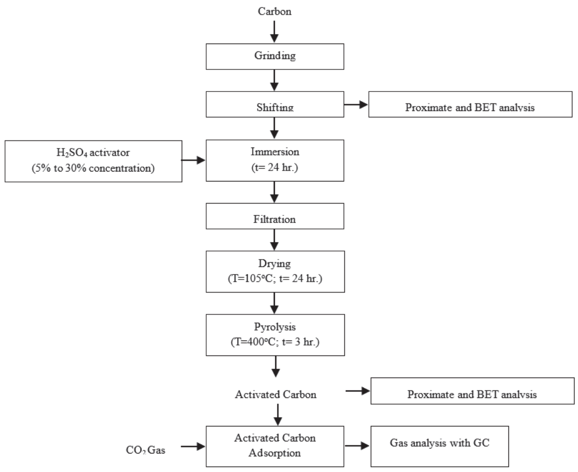

Fig. 2. Process diagram for CO_2 adsorption

Proximate analysis was used to know the characteristic of carbon adsorbent. The surface area, total pore, and diameter of the adsorbent were known by BET (Brunaurer, Emmet, and Teller) analysis. The gas outlet from the column also analyzed the CO_2 concentration using gas chromatography (GC).

2.1 Captions/numbering

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3 Equations and Mathematics

3.1 Activated Carbon Properties by Proximate Analysis

From the proximate analysis, the ash content of the activated carbon was decreased with a higher concentration of sulfuric acid used to activate the carbon. Figure 3 indicated the ash content of 25% H_2SO_4 activator was relatively low (3.93%), and the fixed

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carbon was 80.01. The ash content should be minimum as impurities of the carbon. With lower ash content, the adsorbing capacity of carbon could be higher. Whereas the higher fixed carbon, the more gas could be adsorbed by the carbon molecules.

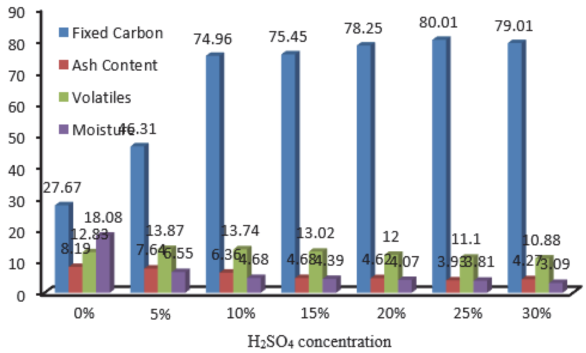

Fig. 3. Characteristic of carbon adsorbent with proximate analysis

The proximate showed the relation between the concentration of H_2SO_4 as the activator of carbon (Fig. 4). With higher H_2SO_4 concentration, the value of fixed carbon was increased but decreased the ash content, volatiles, and dried moisture of carbon. So, the adsorption ability of carbon was higher with the increase of activator concentration. Using of sulfuric-based activator affected the lowering of the total pore volume and specific surface area [9]. Stronger the H_2SO_4 solution, the potency of functional group formation was increased.

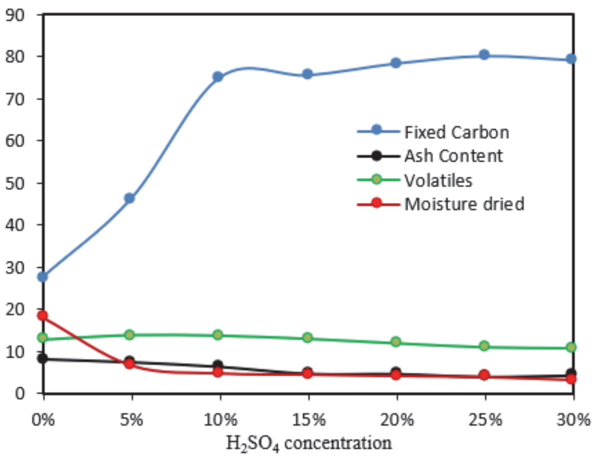

Fig. 4. Correlation between concentration of H_2SO_4 and activated carbon characteristics from proximate analysis

3.2 Activated Carbon Characteristic Analysis Using BET

The characteristic of carbon adsorbent is like porous solid that consists of mostly free carbon bonded by covalent force. By that structure, the activated carbon was non-polar. Besides the composition and polarity, the pore structure was important to analyze. The pore structure is linked to the surface area of the adsorbent. Smaller pore size resulted in higher surface area and increased the adsorption velocity. As shown in Figure 5, the BET analysis results in an increase in H_2SO_4 activator concentration followed by an increased in surface area and total pore volume. In contrast, the pore average was decreased along with the increase in activator concentration. With 25% H_2SO_4 achieved the best condition, the surface area was 5992.65 m2/gr with a total pore volume of 39.4620 cc/gr and a pore average of 2.6072 Å. Higher activator concentration would break the hydrogen bonds or oxidize surface molecules so that carbon's chemical and physical properties would transform. The surface area would get bigger and effected the adsorption ability.

Figure 6 showed higher activator concentration would be followed by the increased surface area and total pore volume, but the average pore radius decreased. The ability of carbon to adsorb carbon dioxide would increase by the increase of molecule size on a similar structure. Adsorption is also affected by the functional group, the double bond placed, and the chain structure of adsorption compound. The 25% and 30% H_2SO_4 concentrations would give the best carbon characteristic.

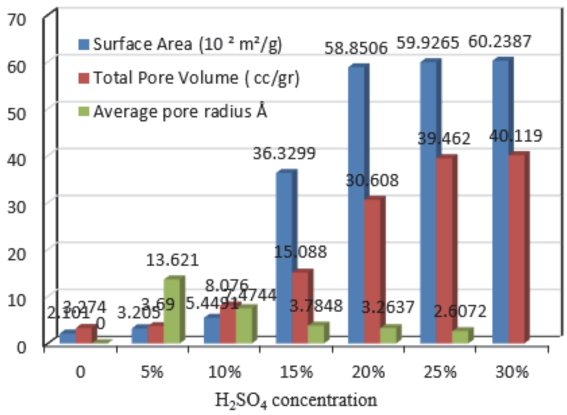

Fig. 5. Characteristic of carbon adsorbent with BET analysis

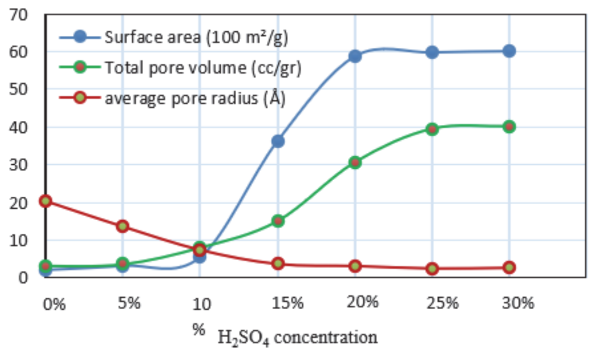

Fig. 6. Correlation of H_2SO_4 concentration and activated carbon characteristics from BET analysis

3.3 Carbon Effectivity Test using GC

The flow rate of carbon dioxide inserted in the column affected the adsorption process. Figure 7 describes the ability of carbon to adsorb CO_2. The percentage of adsorbed CO_2 would increase with a lower gas inlet flow rate. The difference of CO_2 adsorbed was 5% to 21% for every decrease in CO_2 inlet rate with the range 0.0022 L/min to 0.0058 L/min. The highest adsorption CO_2 ability of carbon was 99.839 with a 0.0022 L/min gas inlet rate.

The percentage of CO_2 adsorbed would increase with higher activator concentration. Sulfuric acid could dissolve the impurities that clog the carbon pore so that acid would open the pore, and the pore surface become wider [11]. Figure 8 indicated the CO_2 adsorb percentage increased with activator concentration. The increase of activator concentration strongly impacted the binding of the compound that passed the carbon. The higher surface area of carbon would lead to carbon adsorption ability enhancement.

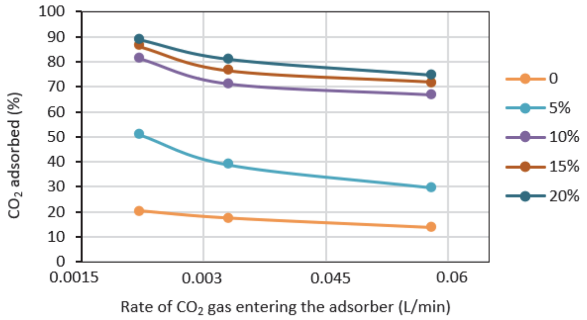

Fig. 7. Correlation of CO_2 flow rate with CO_2 adsorbed

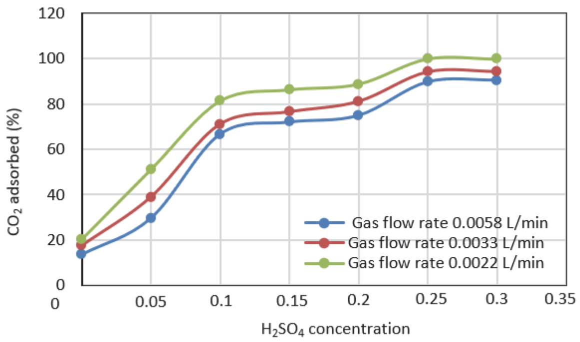

Fig. 8. Correlation of H_2SO_4 concentration and CO_2 absorbed

4 Conclusion

Chemical and physical processes were carried out in activated carbon. The favourable properties of activated carbon were obtained by 25% H_2SO_4 as an activator and pyrolysis at 400°C for 3 hours. The activated carbon characteristics by the proximate analysis were 3.93% ash content and 80.01 fixed carbon. In BET analysis, the adsorbent surface area was 5992.65 m2/gr, 39.4620 cc/gr total pore volume, and 2.6072 Å pore average radius. The effectivity of activated carbon absorbance of CO_2 was 99.839% at a 0.00221 L/min gas inlet rate.

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