Comparing Characteristics of Charcoal and Activated Carbon from Oil Palm Fronds

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Abstract. This study aimed to make use of oil palm fronds that contained cellulose, hemicellulose, and lignin in manufacturing of charcoal through pyrolysis and activated carbon through pyrolysis and impregnation process. To do so, oil palm fronds were pyrolyzed at 150 °C, 200 °C, and 250 °C for 90 minutes. Afterwards, the pyrolyzed fronds or charcoal were smoothed with a ball mill, sieved to 140 meshes, and impregnated using a Sodium Carbonate (Na2CO3) for 24 hours at a concentration of 0, 2.5, 5, and 7.5 % (w/v). The effect of impregnation process has been investigated. Activated carbon with the highest iodine value of 565.19 mg/g was obtained at 5.0 % (w/v) of sodium carbonate at temperature of 250 °C and the charcoal was 493.5 mg/g. The activated carbon has 6.55% of water content, 13.11% of ash content, 13.46% of volatile matter, 67.67% of fixed carbon. The charcoal has 4.21% of water content, 17.91% of ash content, 14.42% of volatile matter, 66.33% of fixed carbon. FTIR Analysis indicated that charcoal and activated carbon tends to be more polar and contained specific bonds of activated carbon. Moreover, SEM analysis also indicated that activated carbon contained coarse and distributed porous.

1. Introduction
A great potential of oil palm plantations in Indonesia has been discovered. This was proven by the production of oil palm fronds that have reached 10.14 million tons. In Indonesia, oil palm frond was mainly utilized for animal food, nitrocellulose, and compost. When in fact, it contains cellulose, hemicellulose, lignin that has great possibility to be used as the resources in the fabrication of activated carbon and charcoal by pyrolysis and impregnation process. This showed that oil palm fronds could be processed further into advantageous products.

To this date, the utilization of activated carbon in Indonesia is still high. The manufacturing industry of activated carbon has been increase faster according to market demand for activated carbon [1]. Demand for activated carbon raise by 9% throughout 2014, with consumption of activated carbon in 2014 at 1.7 million tonnes per year.

There are two stages in making charcoal and activated carbon. The first stage is called pyrolysis, which is combustion process in the absence of oxygen and other chemicals. Meanwhile, the second stage, namely impregnation. Impregnation is done to enlarge the pore of charcoal by breaking the hydrocarbon bond or oxidizing the molecule surface, and it will cause the nature of charcoal is changing. The surface area become larger and has an effect as an adsorbent [2]. Thus, the purpose of
this research is to converse oil palm fronds as waste in plantation into advantage products such charcoal or activated carbon according to Industrial National Standard 06-3730-1995.

2. Method
There are several stages in the manufacturing process of activated carbon from oil palm fronds: (1) preparation of oil palm fronds; (2) production of charcoal; (3) production of activated carbon; and (4) Properties analysis of charcoal and activated carbon as a final product. First, a small pieces of oil palm fronds was dried in the oven at 105 °C, until it has a constant weight. Then, the pyrolysis process was carried at 150 °C, 200 °C, and 250 °C for 90 minutes. Next, the charcoal was put into the oven to make it dry, followed by smoothing with a ball mill to get a particle size of 140 mesh. In performing chemical activation, Sodium Carbonate as an activator (Na₂CO₃) with a concentration of 0 %, 2.5%, 5%, and 7.5% was used. The process was conducted in the oven at the temperature of 80°C for 2 hours and impregnated at room temperature for 24 hours. The resulting activated carbon was filtered, washed using distilled water, and dried using the oven. In the end, the final product of charcoal and activated carbon was analyzed using several approaches. This includes analysis of charcoal yield, proximate analysis, and quantitative analysis.

3. Results and Discussion

3.1. Charcoal yield
As we can see from Figure 1, there is an inverse relationship between charcoal yield and temperature, in a way that there is a decrease of charcoal yield when the pyrolysis temperature increased. Several scholars found out that this is due to the process of decomposition of raw materials [3] as well as producing of non-condensable gases. Figure 1 also indicated that the resulting charcoal yield was range between 30.63% and 32.80 %, which is consistent with findings from previous research.

![Figure 1. Charcoal yield](image)

3.2. Water content
From Figure 2, increase in water content is proportional to the increase in activator concentration. Increase concentration of the activator will lead to better dissolution process of the compound [1,4]. Therefore the pores will increase, causing an increase of activated carbon to adsorb water from the air. Similar with charcoal yield, there is also an inverse relationship between the pyrolysis temperature and water content of the charcoal and activated carbon. The increase in temperature leads to the decrease in water content, which in the end will increase the formation of the pores. Comparing with the Indonesian standard, both charcoal and activated carbon have achieved the requirement of Industrial National Standard 06-3730-1995 for water content.
3.3. Ash content

In contrast with the effect of temperature on charcoal yield and water content, the increase in ash content is directly proportional to the increase in temperature of pyrolysis and causes the accumulation of inorganic elements [5]. In general, there is a difference in composition of ash content between activated carbon and charcoal, in which ash content of activated carbon is lower than the charcoal. This is due to the fact that charcoal still contains higher tar and organic minerals and will trigger the formation of metal oxides that increase the ash content on activated carbon [6]. Moreover, the amount of ash content is increased because of the formation of mineral salts during the pyrolysis as well as the increasing amount of silica content [3].

3.4. Volatile matter

The concentration of activator has an effect in reducing volatile matter due to its ability to modify the structure and properties of activated carbon. Sodium carbonate will degrade organic material and will weaken the surface structure of the activated carbon. After that, volatile matter will be released and establish the microporous structure of activated carbon [6]. Other findings indicated that the increase in temperature will improve the decomposition performance of non-carbon compounds and will reduce volatile matter as well [7].

3.5. Fixed carbon

The increase of activator concentration has an effect in increasing the percentage of fixed carbon, while the increase in temperature are causing fixed carbon concentration to fluctuate. Value of fixed carbon content is influenced by the water content, ash content, and volatile matter of activated carbon [8]. Other research also found out that cellulose and lignin content can also affect content of fixed carbon [9].
Figure 4. Volatile Matter of Activated Carbon and Charcoal (0% of conc. of Sodium Carbonate)

Figure 5. Fixed Carbon of Activated Carbon and Charcoal (0% of conc. of Sodium Carbonate)

3.6. Iodine number
As can be seen from Figure 6, pyrolysis temperature has an effect in increasing iodine number of both activated carbon and charcoal, since it increase the pressure in the pyrolysis reactor, thus facilitating disconnection of carbon chain. It also causes the increase in number of shifting carbon plates and will induce hydrocarbon compounds and other organic compounds to break out during pyrolysis process [4]. Furthermore, it increases surface area of the charcoal and activated carbon pores [10].

Higher activation temperature will lead to better creation of pores, which will increase the adsorption capacity. The C and H bonds in the charcoal or the activated carbon are completely released, and this resulted in a shift of the crystallite carbon plate forming new pores. As expected, the iodine numbers of activated carbon are directly proportional with activator concentration. Higher concentration of activator will make it easier to bind with tar and volatile substances from pyrolysis [10]. There is a difference in the iodine number between charcoal and activated carbon, in a way that the former was lower than the latter. The impregnation by the activator is capable to reduce the non-carbon compound so that it will enlarge the pore surface of activated carbon [5].

3.7. SEM analysis
As can be seen from Figure 7, there is a small pore surface on a charcoal. On the other hand, there is a more pore distribution and cavity on the surface of activated carbon. The evaporation and dissolution process of the non-carbon compounds has resulted in different structures of the pores. Comparing between charcoal and activated carbon, the surface of the latter was wider and diffuse, which is rougher and more irregular compared to the former. Activator can have a role in enlarging the pores of activated carbon, which in the end will expand the surface of the adsorption.
Figure 6. Iodine Number of Activated Carbon and Charcoal (0% of conc. of Sodium Carbonate)

Figure 7. Scanning Electron Microscope (200x) of Charcoal (a) and Activated Carbon (b)

3.8. FT-IR analysis
Figure 8. Fourier Transform Infrared Spectrum of Charcoal (A) and Activated Carbon (B)

Table 1. Comparison of Spectrum Infrared of Charcoal and Activated Carbon

| No | Functional Group | Charcoal | Activated Carbon |
|----|------------------|----------|------------------|
| 1. | O-H              | 3425.58  | 3406.29          |
| 2. | -CH₃             | 1442.75  | 1438.90          |
| 3. | C-O              | 1280.73  | 1114.86          |
| 4. | =C-H             | 756.10   | 759.95           |

Charcoal and activated carbon have a peak that is not much different as shown in Table 1. It is proven that in this study, the resulting compound is charcoal or activated carbon. Based on the results of FTIR, the presence of -CH₃ and =C-H bonds indicate that both charcoal and activated carbon has contained alkane group which is the specific bond for charcoal or activated carbon and aromatic alkene group which is the compounds making up the hexagonal structure of charcoal and activated carbon. The presence of OH and C-O bonds indicate that the activated carbon or charcoal tends to be more polar. Thus, activated carbon or charcoal can be used as a polar adsorbent such as for water purification, sugar, alcohol or as a formaldehyde emission absorber [5].

4. Conclusions

Characteristics of activated carbon with the highest iodine number of 565.19 mg/g was obtained at 5.0 % (w/v) of sodium carbonate at temperature of 250 oC. The activated carbon has 30.64% of charcoal yield, 6.55% of water content, 13.11% of ash content, 13.46% of volatile matter, 67.67% of fixed carbon, while the charcoal has 4.21% of water content, 17.91% of ash content, 14.42% of volatile matter, 66.33% of fixed carbon, and 493.5 mg/g of iodine number. The porous of charcoal or activated carbon has a performance in the adsorption process, and showed by the iodine number value of 565.19. FTIR Analysis indicated that both charcoal and activated carbon tends to be more polar and contained specific bonds of activated carbon. SEM analysis indicated an activated carbon contained coarse and distributed porous.

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