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Utilization of oil palm fronds in producing activated carbon using Na_2CO_3 as an activator

S Maulina^{1,2*}, FN Anwari¹

¹Department of Chemical Engineering, Faculty of Engineering, Universitas Sumatera Utara

²Sustainable Energy and Biomaterial Center of Excellence, Faculty of Engineering, Universitas Sumatera Utara

*E-mail: maulina_harahap@yahoo.com

Abstract. Oil Palm Frond is a waste in palm oil plantations that have the potential to be processed into more valuable products. This possibility is because of the presence of cellulose, hemicellulose, and lignin in oil palm fronds. Therefore, this study aimed to utilize oil palm fronds in manufacturing of activated carbon through pyrolysis and impregnation that meets the requirements of the Industrial National Standard 06-3730-1995. The palm-fringed oil palm fronds were pyrolyzed in reactors at 150°C, 200°C, and 250°C for 60 minutes. Subsequently, the charcoal produced from the pyrolysis was smoothed with a ball mill, sieved with a size of 140 meshes, and impregnated using a Sodium Carbonate (Na_2CO_3) for 24 hours at a concentration of 0 %, 2.5%, 5%, and 7.5 % (w/v). The activated carbon has 35.13% of charcoal yield, 8.6% of water content, 14.25% of ash content, 24.75% of volatile matter, 72.75% of fixed carbon, and 492.29 of iodine number. Moreover, SEM analysis indicated that activated carbon porous are coarse and distributed.

1. Introduction

This research aimed to utilize oil palm fronds as one of the waste resulting from oil palm plantations into more valuable products, such as charcoal or activated carbon that follows the Industrial National Standard 06-3730-1995. The main idea of this research was based on the fact that oil palm plantations in Indonesia is keep expanding in almost all provinces. Currently, Indonesia is classified as a first world producer of palm oil followed by Malaysia [1]. The untapped potential of oil palm plantations in Indonesia can be reflected from the fact that there are 10.14 million tons of oil palm fronds waste that was produced by an area of oil palm plantations. Unfortunately, the utilization of oil palm fronds in Indonesia was mainly for animal food, nitrocellulose, and compost. One of the solid wastes produced from oil palm plantation is oil palm frond, which contains cellulose, hemicellulose, and lignin. This content shows great potential to be used as raw material in the manufacturing of charcoal or activated carbon using pyrolysis and impregnation process. In other words, oil palm fronds could be processed further into useful and economically valuable products.

Consumption of activated carbon in Indonesia is still relatively high. It is due to the widespread use of activated carbon in the industrial sector, such as fisheries and health sector [2]. The domestic activated carbon manufacturing industry has been progressing rapidly due to the increasing market demand for activated carbon both inside and outside the country [3]. This is supported by the fact that demand for activated carbon increases by 9% annually throughout 2014, while global activated carbon



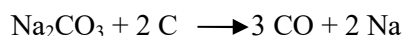
consumption in 2014 is estimated at 1.7 million tonnes per year. Furthermore, the number of activated carbon exports in Indonesia amounted to 21.652.271 kg per year in 2011 [2].

Hence, the purpose of this research is to utilize oil palm fronds as waste into products that have more value, for instance charcoal or activated carbon-based on Industrial National Standard 06-3730-1995.

2. Theory

Charcoal or activated carbon can be made through two stages, namely pyrolysis and activation or impregnation. Pyrolysis is an indoor combustion process in the absence of oxygen and other chemicals, whereas impregnation is required to convert combustion products into adsorbents that have larger surface area. Impregnation is the treatment of charcoal which aims to enlarge the pore by breaking the hydrocarbon bond or oxidizing the surface molecule so that the char is changing in nature, either physics or chemistry, for example, the surface area is larger and has an effect on the adsorption process [7].

In the activation of the charcoal chemically, the pyrolyzed raw material is then impregnated with chemical activator such as acids, bases or salts and heated in an inert space [4]. Although the use of alkali hydroxides and acids such as KOH and HCl shows progress on the high surface area of activated carbon, but the nature is corrosive, harmful, and environmentally unfriendly. The use of alkali salts, such as carbonates can be another alternative to acid or base replacement. Examples of carbonate salt activating agents are Li_2CO_3 , Na_2CO_3 , and K_2CO_3 , with activating mechanisms as the following [5]:



A sodium carbonate solution is used because it is readily available, completely soluble in water and will not produce metal oxide if it decomposes and can decrease metal content, and has high alkalinity [6].

Charcoal or activated carbon may be used as good adsorbent agent for gas purification processes and removal of organic pollutants from water, such as in liquid waste. The texture and properties of the activated carbon depend on the initial treatment, the used of activation process, the number of process provided, the kind of activator agent, and the time or the process in the application of activated carbon itself [7], for example in adsorption of organic matter is using silica gel and active alumina, zeolite, molecular filters, and synthetic resins. Among of these examples, activated carbon is more efficient in eliminating many pollutants, either organic, inorganic, or biological [8].

3. Method

The process of manufacturing activated carbon from oil palm fronds is done through several stages, namely: oil palm fronds preparation, charcoal production, activated carbon production, and product analysis (charcoal and activated carbon).

First, oil palm fronds are cut into small pieces and dried in the oven at 105°C until the weight of the oil palm fronds are constant. Analysis of raw materials such as water content analysis using the oven. After that, the palm-fringed oil palm fronds was inserted into pyrolysis reactor. Pyrolysis was conducted at 150°C , 200°C , and 250°C for 60 minutes to produce charcoal.

The charcoal produced from the pyrolysis was dried using the oven and smoothed with a ball mill, sieved to obtain a particle size of 140 mesh. Chemical activation was done by using Sodium Carbonate activator (Na_2CO_3) with a concentration of 0 %, 2.5%, 5%, and 7.5% in the oven at the temperature of 80°C for 2 hours and then impregnated for 24 hours at room temperature. Activated carbon was filtered to separate from the filtrate. Then, activated carbon was washed using distilled water until the pH of 7. After that, activated carbon was dried using the oven.

The product analysis of charcoal and activated carbon includes charcoal yield, the proximate analysis in the form of water content, ash content, volatile matter, fixed carbon and qualitative analysis, such as scanning electron microscopy and iodine number value.

4. Result

4.1. Yield of Charcoal

The relationship between pyrolysis temperature and yield of charcoal as shown in Fig. 1.

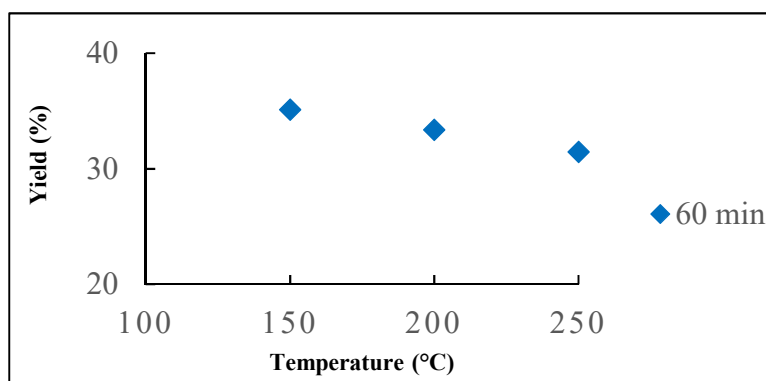


Figure 1. Yield of Activated Carbon

Fig. 1 revealed that there is an decrease in the yield of charcoal along with the increase of pyrolysis temperature. The decrease in yield is due to the increase of pyrolysis temperature. The higher the pyrolysis temperature, the less charcoal produced because the components that contained in raw materials such as water and volatile substances will be decomposed [10] [11], as well as the formation of non-condensable gases such as CO_2 , CO , H_2 , CH_4 and some hydrocarbons [12].

The yield of charcoal is ranged from 31.40 - 35.13 %.The result of this study is same as the previous researchers, where the yield value of oil palm fronds yielded ranged from 32 to 33% [9].

4.2. Water Content

Water content as a function of temperature and concentration of activator can be seen in Fig. 2.

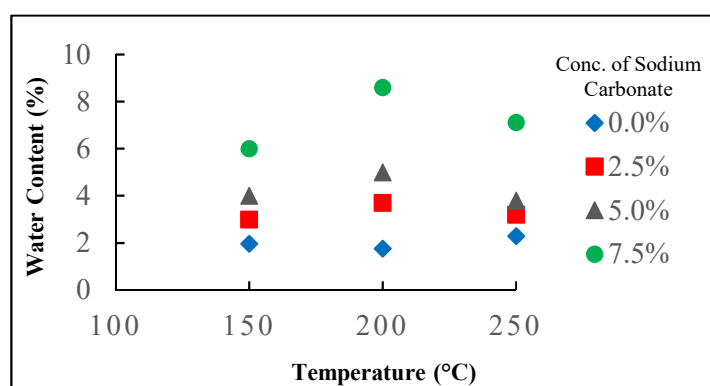


Figure 2. Water Content of Charcoal and Activated Carbon

The value of water content increases with the higher concentration of the activator. It is due to the higher concentration of the activator, the dissolution process of the remaining pyrolysis, such as tar and organic mineral on the surface of the activated carbon will be better. As a result, the resulting pores and the surface area will increase, causing an increase in performance of activated carbon to adsorb water from the air [3] [12].

The water content of the charcoal and activated carbon is lower along with the increasing of pyrolysis temperature. It causes the formation of the pores will increase as well. The bonds of C and H

on charcoal are completely released resulting in shifting the crystallite of carbon plate forming new pores and developing the pores that have been formed [13]. It causes the higher performance of the charcoal or activated carbon to adsorb water from the air as well [14].

The value of water content of the charcoal is lower than that of the activated carbon. It is because the presence of the activator will dissolve the remaining pyrolysis and organic mineral tar on the charcoal surface. The resulting the pores will be more numerous and the surface area will increase as well, leading to improve the properties to adsorb water from the air and the hygroscopic ability of activated carbon [3].

Both charcoal and activated carbon have fulfilled the requirement of Industrial National Standard 06-3730-1995 for water content of activated carbon.

4.3. Ash Content

Ash content in charcoal and activated carbon as depicted in Fig. 3.

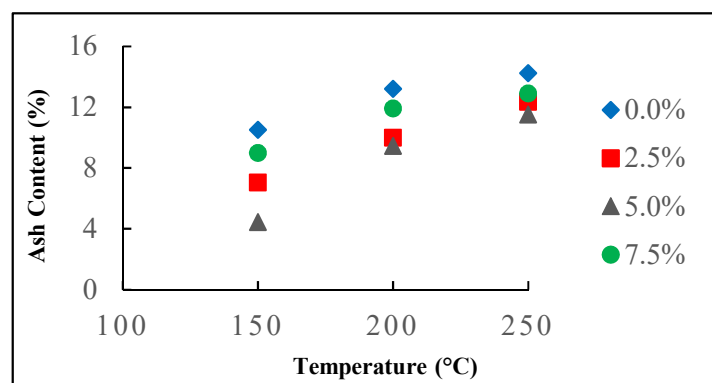


Figure 3. Ash Content of Activated Carbon and Charcoal

Ash content increases along with pyrolysis temperature and causes the deposit of inorganic elements to stick more to the charcoal or activated carbon [14].

Ash content increases with the increasing of activator concentration causing the organic compound of activated carbon is to decrease, but the content of the inorganic compound is relatively fixed. The content of ash content will increase as organic compounds are lower [14].

The ash content of charcoal is higher when compared to the activated carbon. It is because a charcoal still contains high tar and organic minerals due to pyrolysis process [14]. The interaction in the reactor during the pyrolysis process causes the formation of inorganic compounds in the charcoal. These compounds trigger the formation of metal oxides so that ash content on activated carbon is higher [14]. The increasing of ash content occurs because of the formation of mineral salts during the pyrolysis. Ash content is influenced by the amount of silica content, the higher the silica content, the higher ash content will be [15].

4.4. Volatile Matter

Volatile Matter in activated carbon and charcoal in this research as shown in Fig. 4.

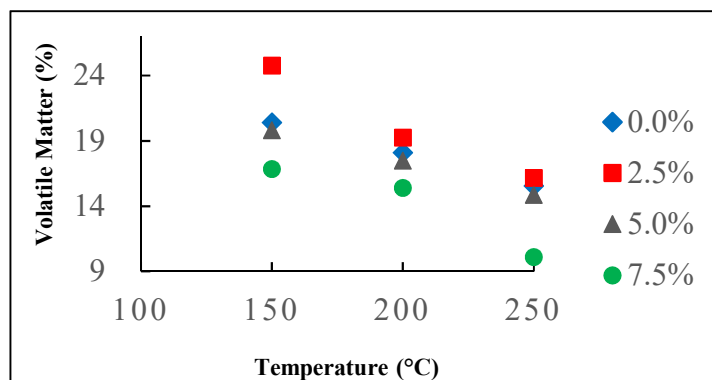


Figure 4. Volatile Matter of Activated Carbon and Charcoal

Volatile matter decreases as the increasing of activator concentration. It is because the addition of activator causes changes in the structure and properties of activated carbon. Sodium carbonate can cause the process of organic material degradation that weakens the surface structure of the activated carbon then releases volatile matter and develops the microporous structure of activated carbon [16].

The pyrolysis temperature increases, the decomposition of non-carbon compounds will be better, so the volatile matter will be lower [17]. At the higher temperatures, the volatile matter will released numerous substance and cause less carbon to form [18]. It is due to the higher pyrolysis temperature, the decomposition of the components contained in raw materials such as water, tar, and volatile matter is also higher [11]. Devolatilization signifies the release of volatile substances from charcoal matrix or activated carbon [19].

The value of the volatile matter on the charcoal is higher than the activated carbon. The impregnation by using the activator is capable of reducing the non-carbon compound that attached to the activated carbon surface and entering the base surface of the charcoal through the pores on the charcoal, so that the presence of the activator will cleanse and enlarge the pore surface [14].

4.5. Fixed Carbon

Fixed carbon of activated carbon and charcoal from oil palm fronds can be shown in Fig. 5.

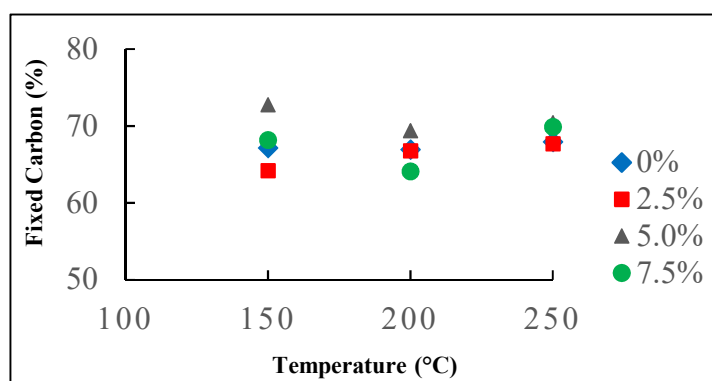


Figure 5. Fixed Carbon of Activated Carbon and Charcoal

The value of fixed carbon increase along with the increasing of activator concentration. The value of fixed carbon fluctuates along with increasing pyrolysis temperature. It is because the value of bound carbon content is influenced by the water content, ash content, and volatile matter of activated carbon

[20]. The fixed carbon content is also affected by cellulose and lignin content that can be converted to carbon atoms [14]

4.6. Iodine Number

Iodine number of activated carbon and charcoal from oil palm fronds can be seen in Fig. 6.

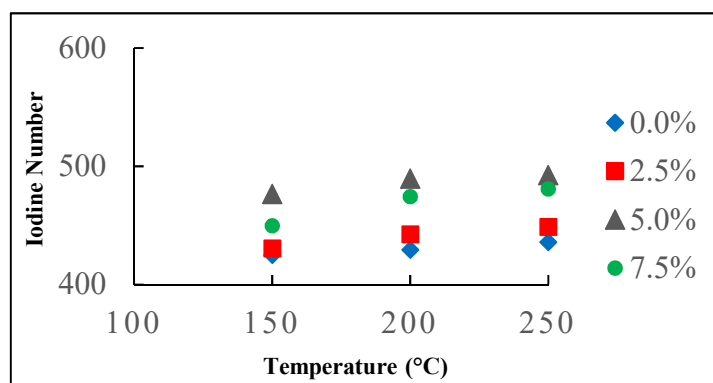


Figure 6. Iodine Number of Activated Carbon and Charcoal

The value of iodine number of charcoal and activated carbon increases as the increasing of pyrolysis temperature. The higher pyrolysis temperature will result in higher pressure in the pyrolysis reactor, thus facilitating disconnection of carbon chain [21] and cause the increase in number of shifting carbon plates and will induce hydrocarbon compounds and other organic compounds to break out during pyrolysis process [12]. This result increases surface area of the charcoal and activated carbon pores [21].

The longer pyrolysis processes can form pores and carbon plates better so as to increase the adsorption capacity of the solution [14]. This is related to the reaction kinetics that cause the higher the activation temperature so the reaction speed will be faster so that the formation of the pores will be better. The bonds of C and H atoms in the charcoal or the activated carbon are completely released resulting in a shift of the crystallite carbon plate forming new pores and developing the pores already formed [14].

The iodine number value of activated carbon increases along with increasing concentration of activator. The higher the concentration of the activator will be easier to bind with tar and volatile matter from pyrolysis. As a result, tar and volatile substances of activated carbon will decrease because of the washing process, so the activated carbon will have an larger surface area [21].

The iodine number on charcoal is lower when compared with activated carbon. The impregnation by using the activator is capable of reducing the non-carbon compound attached to the activated carbon and it will cleanse and enlarge the pore surface [14].

4.7. SEM Analysis

Figure 7 shows a comparison of surface characteristic between charcoal and activated carbon.

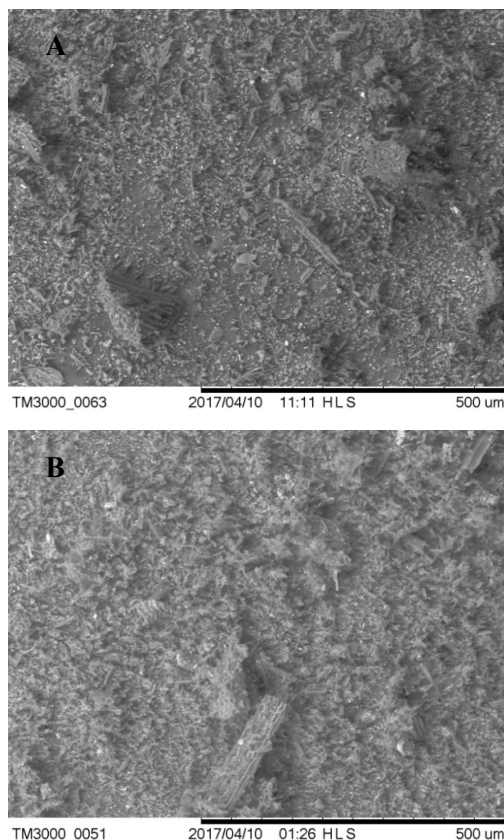


Figure 7. Scanning Electron Microscope (200x) of Charcoal (a) and Activated Carbon (b)

Fig. 7 shows a charcoal has a relatively small pore surface and activated carbon has more pore distribution and cavity on its surface. The structure of the pores formed may result from the evaporation and dissolution of the non-carbon compounds in the raw material. Activated carbon also has a rough and irregular surface that is wider and diffuse compared to charcoal. The presence of the activator can enlarge the pores of activated carbon and expand the surface of the adsorption.

5. Conclusion

The highest yield of charcoal from oil palm fronds is obtained on 35.13% at the temperature of 200 °C. The highest value of proximate analysis is water content of 8.6%, ash content of 14.25%, volatile matter of 24.75%, and fixed carbon of 72.75%. These results indicated that the charcoal or activated carbon from palm oil fronds had fulfilled the requirements of Industrial National Standard 06-3730-1995.

The porous of has a performance in the adsorption process. It proved by the iodine number value of 492.29. Moreover, SEM analysis indicated a porous activated carbon that is coarse and distributed.

6. Acknowledgments

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