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Actived carbon from teak wood, jackfruit wood, and mango wood pyrolysis process

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Abstract. Activated carbon is one of the basic needs in food processing. Activated carbon can be improved from rock, wood and bone processing. This study aims to determine the quality of activated carbon pyrolysis processing from various woods using high temperatures ranging from 500-750 °C. The wood to be made into activated carbon is teak, mango, and jackfruit. Where teak, mango, and jackfruit are the types of wood used for fuel in industrial tofu boilers. The results of this combustion usually only become waste as charcoal boiler waste. The results of combustion contain carbon which can be used as this activated carbon. The quality of activated carbon is seen from the quality test based on SII and SNI. The results of the tests carried out that the best quality activated carbon is activated carbon which is activated by using heat at a temperature of 750 °C with a water test value of 1.01%, evaporator 15.12%, 2.3 ash, carbon-bound 82, 5%, iodine uptake rate 314.15 mg/gram, crystalline rate 40.886% with XRD analysis, pore diameter 8,72 μm, and chemical composition (% b) 95.94% C, 0.33% SO_3, 2.06 % chloride , 0.49% K_2O, 0.79% Calcium oxide, and 0.38% Cuprum oxide using SEM-EDX.

1. Introduction

Data from the Ministry of Industrial Affairs of the Republic of Indonesia (2016) documents that the country's industrial growth has improved to 5.3%. One of the industries to have been positively growing is the tofu industry. The tofu industries in Indonesia were dominated by small enterprises, and they are vastly growing as the population grow. To improve the production effectiveness and its manufactured quality the industries greatly rely upon a boiler system as the pivotal industrial system.

The boiler is an energy conversion machinery, which converts water into steam as the temperature reaches 500 °C. The conversion occurs by heating from the fuel burning in the boiler fuel chamber. In tofu industries, the boiler fuel is sourced from woods. The woods fueling the process are varied from, but not limited to, teakwood, mango wood, to nangka wood. In the boiler system, the woods are burnt to produce heat for processing the water into the necessary steam. The burning takes place within a burning chamber on a continual basis by inserting the fuel and air from the outside of the chamber. The boiler in-chamber burning results in *ash* and arang boiler wastes as the side-product of the wood burning. The black, light, fragile, and stone-like charcoals are composed of 85%-98% carbon with the remaining proportions consisting of *ash* and other chemical compounds. To improve the economic value of the post-burning arang boiler, a process is necessary to convert into the active carbon [1].

Active carbon is an amorphous carbon compound produced by carbon-or charcoal-containing substances treated with a specific way to get wider surfaces [2]. The more advance of technology in

Indonesia has led to the higher needs for the active carbon, being astronomically high as 35,942 tons annually. The active carbons are used for refining liquids and gases, separating mixtures, filtering and preventing bad smells, conserving colors and avoiding bad tastes in foods, and being a catalyst due to their large surface with a low intrinsic catalytic activity [3].

This study aimed at finding out active carbon characteristics in boiler charcoal wastes under the Industrial Standard of Indonesia (SII) No. 0258-79, and National Standard of Indonesia (SNI) No. 06-3730-1995 (see table 1) [4].

Table 1. Quality threshold standard for active carbon

Requirements	Parameters	
	SII No. 0258-79	SNI 06-3730-1995
Missing parts during heating at 900 °C (volatile matter)	Maximum 15%	Maximum 25%
Water contents	Maximum 10%	Maximum 15%
Ash contents	Maximum 2.5%	Maximum 10%
Bound carbon content	-	Minimum 65%
Absorption rate towards I_2 solution	Minimum 200 mg/gr	Minimum 750 mg/gr

In addition to physical and chemical tests, the active carbons were also subject to other tests, such as that of crystallinity using XRD method and morphological and chemical composition method using SEM-EDX (*Scanning Electron Microscope-Energy Dispersive X-Ray*) method.

2. Research Method

2.1 Materials
Materials used for the research experiment consist of as the followings: boiler charcoal wastes from teakwood, mango wood, and nangka wood; natrium thiosulphate; iodine; kalium iodide; amylum indicator; and aquadest.

2.2 Equipment
This research used the following equipments: leibig cooler; adaptor; erlenmeyer; buret; infrared thermometer; stirring stick; cone; scale glass; beaker glass; filter paper; and stative.

2.3 Experimental design
2.3.1 Analyses of active carbon quality. The experiment performed analyses of the active carbon quality consisted of analyses of water content, vaporizing substance rate, *ash* rate, bound carbon rate, and absorption rate towards iodine solution.

a. Analysis of water content
1 gr active carbon was dried in an oven at a temperature of 105 °C for three hours. The dried active carbon was then put back into desicator. This process was repetitive until the experiment had obtained the constant weight to determine water content percentage (%).
b. Analysis of vaporizing substances
Porcelain bow that contained samples of the water content was covered and the cover was tightened by nichrome wire and then put into an electrical chamber for six minutes. Prior to this process, initial heating was performed at the bottom of the chamber for three minutes. After the vaporization had completed, the *bow* was put into the desiccator until the weight had been constant for weigh in.
c. Analysis of ash content
Bow with the water content and vaporizing substances rate were used for determining the *ash* content. To this end, the bow was put into the chamber and gradually heated from chamber temperature to 600 °C for six hours. After that, a cooling process had to take place in the desicator to obtain the constant weight for weigh in.
d. Analysis of bound carbon content

The determination of the pure active carbon content was done by calculating a lapse between one hundred percent and the results of the kadar abu + vaporable substances.

e. Analysis of absorption rate of iodine solution
The active carbon obtained was milled, scaled at 1 gr, and put into the erlenmeyer. This test sample was added in by 25 ml iodine solution and stirred for 25 minutes. Following this process, the sample was filtered by a filter paper, and the result would be taken up to 10 ml for a titration using thiosulphate with an indicator of 0.1 N amylum indicator. The titration endured until the solution in this experimental sample was obtained. Bow with the water content and vaporizing substances rate were used for determining the *ash* content. To this end, the bow was put into the tanur and gradually heated from chamber temperature to 600 ◦C for six hours. After that, a cooling process had to take place in the desicator to obtain the constant weight for eventual weigh in.

2.3.2 Crystallinity rate test. The crystallinity rate test applied with an XRD method to find out the crystallite structure of a matter whether it had a high crystallinity structure.

2.3.3 Pore structure and active carbon composition test. The pore structure and active carbon chemical composition test applied with a SEM-EDX (*Scanning Electron Microscope-Energy Dispersive X-Ray*) method. This analysis had objectives to find out the topography of a matter's surface due to a change in carbonization temperature and to document its chemical composition.

2.4 Research procedure
2.4.1 Preparation stage. The preparation stage began with making constant chamber temperatures for operating the boiler fuel at 550, 600, 650, 700, and 750 ◦C and the wood used. The stage was when the boiler charcoal wastes were selected.
2.4.2 Examination stage. The selected boiler charcoal wastes were a punt in a crusher and made into uniformed sizes using a 100mesh screen. Once the uniformed sizes had been obtained, the active carbons were subject to the tests of water content, ash content, vaporized substances content, bound carbon content and iodine absorption rate content to get the preferable results. When the preferred results had been obtained, the samples were subject to crystallinity test using XRD method and morphological and chemical composition test using SEM-EDX (*Scanning Electron Microscope-Energy Dispersive X-Ray*) method.

3. Results and discussion

3.1 Water content
The examined active carbons had 1.01%-4.17% water contents. Figure 1 illustrates that the water content decreased as the carbonization temperature increased. Sjostrom in [6] writes that the higher carbonization temperature caused, the higher dehydration process within the carbons so that the water contained decreased due to evaporation. Even though at some points the water content increased, this study found that the water content still fulfilled the quality threshold standard of the SII No. 0258-79 with a maximum parameter of 10% and the SNI No. 06-3730-1995 with a maximum parameter of 15%.

The examined carbons of the teakwood had the lowest vaporized substance rate (15.12%) at the carbonization temperature of 750 C, whereas the highest rate was obtained by mango wood (36.62%) at 600 C. Figure 2 indicates the effect of carbonization temperature on the lower vaporized substance rate of the active carbons in the boiler charcoal wastes due to increasing carbonization temperature. Pari [7] concludes that the increasing carbonization temperature tends to lower the vaporized substance rate. It happens because at high temperature the decomposition process of non-carbon compounds occurred perfectly. Results of the test of the vaporized substance rate had fulfilled the active carbon quality threshold standard of the SNI 06-3730-1995 with a maximum parameter of 25%, i.e., active carbon from the teakwood at 600-750 C, *nangka* wood at 650-750 C, and mango wood at 650-750 C. However, these results did not fulfill the active carbon quality threshold standard of the SII 0258-79, which requires a maximum level of 15%, so that the carbonization temperature still needed to increase.

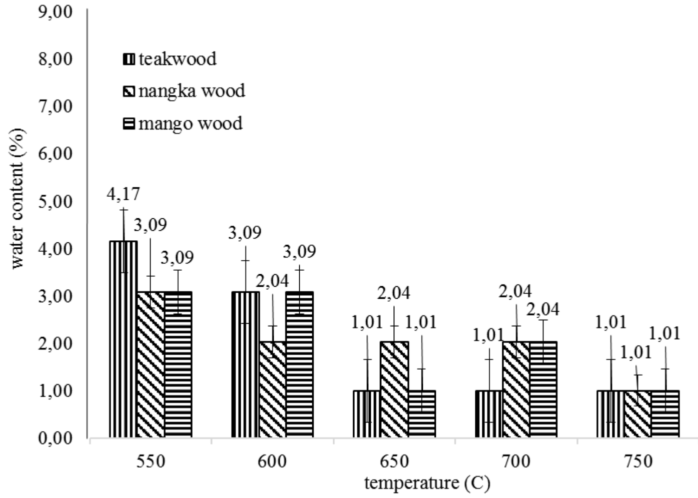

Figure 1. Active carbon water content

3.2 Vaporized substance rate

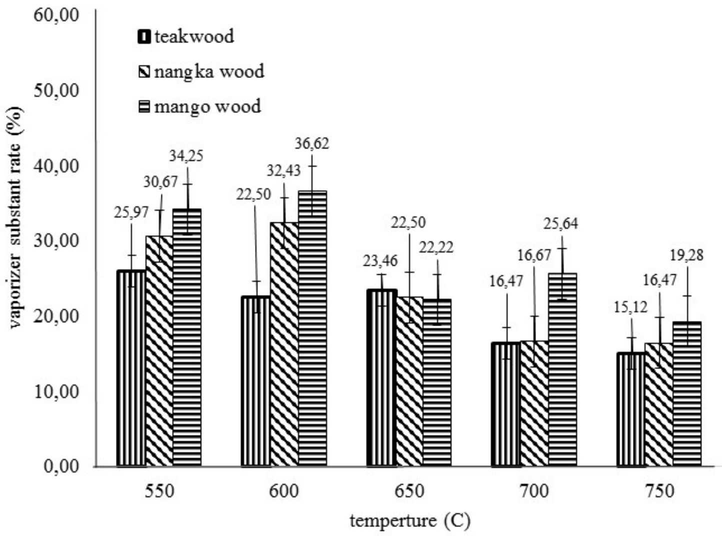

Figure 2. Active carbon vaporized substance rate

The examined active carbons revealed that the ash content ranged from 0.54% to 5.06%. These results had fulfilled the theoretical requirement that the higher carbonization temperature caused the higher ash content, as evident in Figure 3. According to [8] the high ash content is caused by to organic substances, such as carbonate salts, phosphate, silica, and sulfate oxidized creating the high ash content, developing deposits of inorganic substances, which tend to embed into the surface of the active carbons. The high ash content will affect absorption rate of either liquid or gas. This study found that the active carbon ash content of the boiler charcoal wastes was still within the quality threshold standard of the SII 0258-79 with a maximum parameter of 2.5%, as found in the teakwood at 550-750 C (rate ranging from 1.32% to 2.38%) and in the *nangka* wood at 550-600 C (rate ranging from 0.54% to 1.34%). Whereas, according to the SNI 06-3730-1995, the ash content had fulfilled the quality threshold standard of the maximum rate of 10%.

3.3 Ash content test

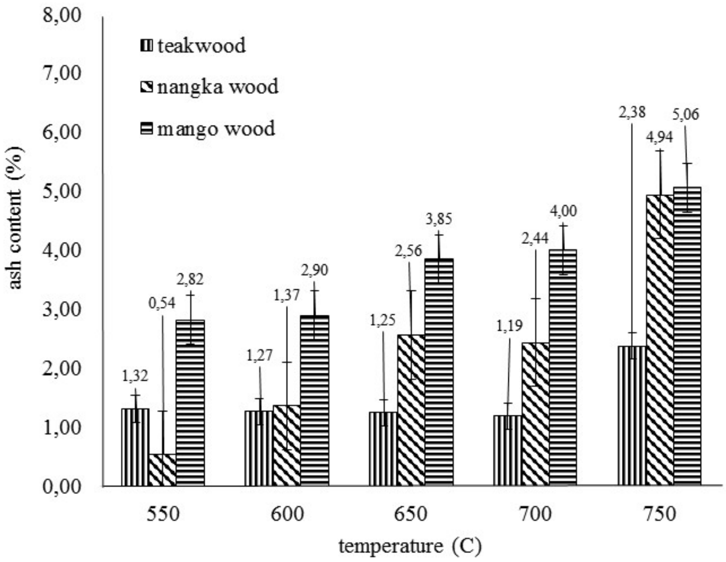

Figure 3. Active carbon ash content

3.4 Bound carbon test

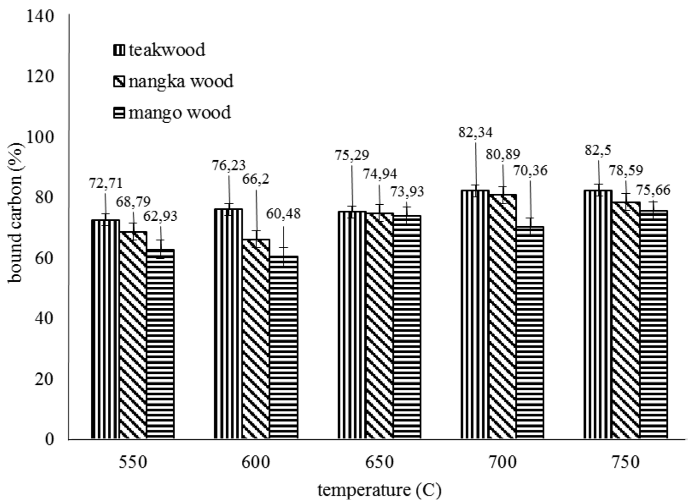

Figure 4. Bound carbon content

Figure 4 documents the bound carbon content in the active carbons from the boiler charcoal wastes. The higher the temperature, the higher the bound carbon content. The bound carbon content was resulted by the decrease of ash content and vaporized substance rate. The higher carbonization temperature, the higher ash content within the active carbons, however, the lower the vaporized and active carbons. Such condition caused the higher bound carbon as the carbonization temperature increased. This study resulted in 6.48%-82.5% bound carbons. The lowest bound carbons were obtained from the experiment using mango wood at 600 C and the highest one was from teakwood at 750 C. Overall, the bound carbons in the active carbons from the boiler charcoal wastes had fulfilled the quality threshold standard of the SNI 06-3730-1995 of the 65% minimum rate.

3.5 Iodine absorption rate

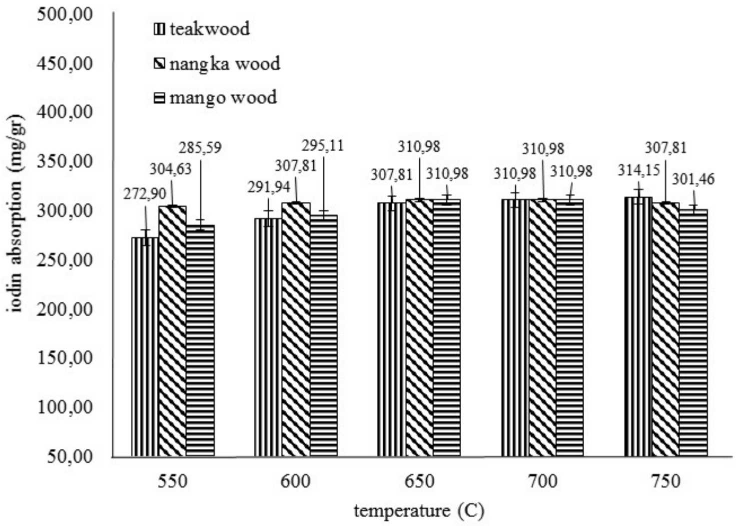

Figure 5. Iodine rate

Figure 5 reveals that the higher carbonization temperature caused the higher iodine absorption rate of the active carbons. It occurred because the higher carbonization temperature, the wider the surface area and the more pore numbers developed in the carbons. Therefore, the absorption rate will increase [9]. This study found that the iodine absorption rate of the active carbons of the boiler charcoal wastes ranged 272.90-314.15 mg/gr. Overall, the iodine absorption rate of the active carbons from the boiler charcoal wastes had fulfilled the SII 0258-79 (minimum rate of 200 mg/gr) but had not fulfilled the SNI 06-3730-1995.

3.6 Crystallinity rate (%)

This study used samples for XRD-based crystallinity rate test were the preferable ones, i.e., active carbons of the boiler charcoal wastes from the teakwood at 750 ◦C. According to the x-ray reading, the crystalinity rate of such samples was 40.88%. The result was higher than the similar result obtained by Ibrahim [9] at 800 ◦C activated with steam for 45 minutes, resulting in 32.82%. The difference in the crystallinity rate between these studies might be due to the differences in materials, charcoal activation process, the interaction between hexagonal layers, and a decrease in crystallinity rate [10]. The higher carbonization temperature, the lower crystallinity rate, and the more amorphous parts in the active carbons. However, too high carbonization temperature may develop more ashes [11]. The high crystallinity rate of the active carbons in this study proved that crystalite change from crystalline into amorphous was lower than the active carbons activated by Ibrahim's experiment in 2015. Such a condition indicated that the active carbons without activation had a lower absorption rate compared to the activated ones. The iodine absorption rate of the current study (314.15 mg/gr) was lower than that of Ibrahim's [9], which recorded 752.7 mg/gr.

The test using SEM-EDX method revealed the preferable result of the active carbons from the charcoal boiler wastes of the teakwood at 750 C. Figure 7 revealed that the active carbon pores developed due to carbonization temperature. The more pore structures at the active carbon surface, the higher absorption rate towards liquid and gas. The pores developed were approximately 8.72 mm, creating macropore. It could be evident by the high iodine absorption rate of 314.15 mg/gr. The pores developed had a van der Walls force, enabling them to drag the molecules for absorption [12] whereas the chemical structures of the teakwood consisted of 95.94% C, 0.33% SO3, 2.06% Cl, 0.49% K2O, 0.79% CaO, and 0.33% CuO. Of all these active carbon compositions, the carbon (C) rate in the active carbons was very high.

3.7 Morphology and chemical compositon of active carbons using SEM-EDX method

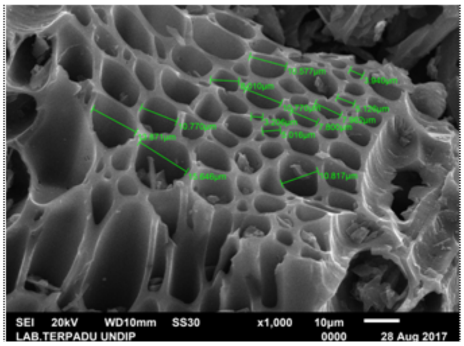

Figure 6. Test of SEM with 1000x magnification

Miranti [13] concludes that better active carbons contain 85%-98% carbons, leaving the rest portions for ashes and other chemical compounds.

4. Closing remarks

4.1 Conclusion

Active carbons from boiler charcoal wastes in this study had been appopriate for being absorption media because they had fulfilled the quality threshold of the SNI 0258-79, but further interventions were necessary to fulfill the quality threshold of the SII 06-3730-1995, in particular the iodine absorption rate. The most satisfying arang boiler wastes during the study was obtained from the teakwood carbonized at 750 °C with the physical characteristics of 1.01% water, 15.12% vaporated substances, 2.3 ash, 82.5% bound carbon, 314.15 mg/gr iodine absorption rate, crystallinity rate of 40.886%, pores diameter of 0.75 µm, and chemical composition (%b) of 95.94% C, 0.33% SO_3, 2.06% Cl, 0.49% K_2O, 0.79% CaO, and 0.38% CuO.

4.2 Recommendation

This study recommended a chemical activation process using specific activator to obtain the iodine absorption rate according to the quality threshold standard of the SNI 06-3730-1995, i.e., 750 mg/gr.

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