Analysis of the electrical impedance and functional group of silicon dioxide (SiO$_2$) from rice straw

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Abstract. Research on silicon oxide (SiO$_2$) from biomass was studied. This study used the biomass of rice straw which is one of the rice agricultural wastes. Rice straw was treated with acid using hydrochloric acid (HCl) before burning. Rice straw charcoal was burned in the furnace at a temperature of 400 °C to 900 °C with a heating rate of 1.7 °C/min for 2 h. The increase in heating temperature was varied at 800 °C, 850 °C, and 900 °C. Silicon dioxide samples were characterized and analyzed based on its electrical properties and functional groups using LCR-meter and FTIR. The extraction of silicon dioxide from rice straw was successfully carried out using a modified method in previous studies. Based on functional group analysis and electrical impedance properties of silicon dioxide rice straw samples, the best result was obtained at 800 °C ignition temperature treatment.

1. Introduction
In recent years, the presence of biomass as a renewable energy substitute for fossil energy has become a public concern. During its development, a number of residues from biomass use were produced but the management of biomass waste was still not optimal. Management of biomass waste that is not optimal will cause environmental pollution and disrupt the health of living things [1]. Biomass is widely used as fuel (bio-fuel) [2] [3]. In addition, biomass can also be used as raw material for various alternative products such as bio-material [4] [5], bio-chemistry [6], bio-adsorbent [7], bio-surfactant [8], and others.

Biomass from rice farming in the form of rice husk and rice straw has not been fully utilized in Indonesia. Rice straw contains lignocellulose which consists of cellulose (32–47%), hemicellulose (19–27%), and lignin (5–24%) which can be degraded with cellulose [9]. Lignocellulose material is widely used as a material for making adhesive boards (particle boards) [10]. In addition, rice straw also has ash content (13-20%) depending on the type of rice, climate, and geographical location of the rice growth [11]. Rice straw ash has a mineral component such as silicon dioxide (SiO$_2$) which is quite high, which ranges from 61.39% to 84.60%.

Silicon dioxide or commonly called silica is a material that has quite high benefits in the industrial field and in everyday life. Silicon dioxide was originally a material that was available in nature, namely in the form of quartz sand. However, the use of silicon dioxide in the form of natural minerals is very wasteful of energy and can cause environmental problems if explored continuously. Thus, silicon dioxide from plant materials is very popular as a substitute for natural mineral silicon dioxide. Silicon dioxide can be extracted from rice straw using several methods, including [12] using NaOH and H$_2$SO$_4$ obtained with purity reaching 90.8% with a temperature treatment at 250 °C, 325 °C, and
575 °C. In addition, a research [13] also used NaOH and H$_2$SO$_4$ but with a temperature treatment of 600 °C, and it was able to produce silicon dioxide with a purity of up to 61.39%. Whereas Nandiyanto et al. [14] synthesized silica particles from rice straw waste with KOH and HCl solutions as extraction agents and heating temperatures of 105 °C. In this study, silicon dioxide particles with a purity of 84.60% have been produced. However, the results obtained still found KCl from the use of KOH extraction agent. Therefore, the extraction of silicon dioxide from rice straw was carried out using HCl solution and tested the effect of heating temperature variations on the process. Furthermore, the extracted silicon dioxide was analyzed for the electrical impedance and functional groups.

2. Materials and methods

The material used in extracting silicon dioxide from rice straw is dried rice straw, Hydrochloric acid (HCl), and distilled water. This research includes the stages of immersion with an HCl solution, making rice straw charcoal, ignition, and characterizations.

2.1. Soaking of rice straw

This process started with drying rice straw with the help of sunlight. The dried straw was weighed about 100 grams and soaked using HCl solution. After that, the rice straw was washed with distilled water to pH 6.5 - 7. After that, the rice straw was dried for 24 h.

2.2. Burning of rice straw

Rice straw from the previous process was weighed and burned in an open room. The combustion process was carried out without the help of fuel. The results were obtained in the form of rice straw charcoal.

2.3. Ignition of rice straw

Rice straw charcoal was placed on a porcelain dish and burned in the furnace. The ignition temperature was set at an initial temperature of 400 °C and held for 2 hours. After that, the temperature was raised to 800 °C and held for 1 hour. The temperature increase in the ignition was varied at 800 °C, 850 °C, and 900 °C. The combustion rate in the furnace was 1.7 °C/min. The results in this process were white rice straw ash.

2.4. Characterization using FTIR and LCR-meter

Fourier Transform Infra-Red (FTIR) was used to determine the formation of SiO$_2$ functional groups from extracted silicon dioxide samples. The FTIR tool used was Perkin-Elmer Spectrum One. The LCR-meter device was used to determine the electrical impedance properties of the sample. The LCR tool used was a Hioki HiTESTER type 3522-50.

3. Results and discussion

The extraction of silicon dioxide in this study is a follow-up study from previous studies [15]. In this study, modifications were made to the extraction process carried out by immersing the acid solution before combustion. This was intended to obtain cleaner silicon dioxide as shown in figure 1. In addition, in this study, temperature variations were carried out in the ignition process and observed the effect that occurred on the results of an analysis using FTIR and LCR-meter.
The results of the characterization of samples using FTIR are shown in figure 2 for each variation of ignition temperature in the range of wave numbers 500 cm\(^{-1}\) – 4000 cm\(^{-1}\). The sample for 800 °C ignition temperature is indicated by a blue pattern. The pattern shows several peaks which are functional groups of certain compounds. The functional groups that indicate the formation of SiO\(_2\) compounds are represented by peaks at wave numbers 470 cm\(^{-1}\), 806 cm\(^{-1}\), and 1102 cm\(^{-1}\). The peak at the wave number 470 cm\(^{-1}\) indicates the bending vibration of the Si-O-Si group [16]. Wave number 806 cm\(^{-1}\) shows an absorption peak for symmetric stretching of Si-O-Si groups [14]. Whereas at wave number 1102 cm\(^{-1}\), the absorption peaks for Si-O-Si groups are seen as asymmetric stretching [14].

Samples at ignition temperature treatment of 800 °C, 850 °C, and 900 °C are marked by blue, red, and green lines in figure 2. The functional groups that indicate SiO\(_2\) compounds in each variation are shown in table 1. Based on the three variations in the temperature of the refining performed to show results with the same pattern, although at 900 °C had a pattern formed at different wave numbers but the difference was not significant. Meanwhile, when it compared with previous studies, these results showed some significant changes. This can be caused by the influence of the temperature applied to the sample. At low temperature treatment, the final result obtained still contains many water molecules.
(OH groups) [14] [15] and other compounds such as graphite (C=C groups) [14]. Meanwhile, if using a high temperature treatment by giving acid treatment before combustion will produce a purer silicon dioxide compound, which is no longer found other groups such as graphite and water molecules.

Analysis using FTIR did not show a significant difference in the effect of ignition temperature. So that additional analysis was needed, one of which was the analysis of electrical properties to determine the differences that occur in the sample. The electrical properties analyzed were impedances which indicate the size of the resistance to alternating current. Analysis of the electrical impedance properties was carried out at frequencies between 0.05 kHz and 100 kHz. The relationship of frequency to the electrical impedance of the sample at a temperature variation of 800 °C is shown in Figure 3, the temperature variation of 850 °C is shown in Figure 4, and the temperature variation of 900 °C is shown in figure 5.

Table 1. Peaks detected in the FTIR result SiO$_2$ samples from rice straw at 800 °C, 850 °C, and 900 °C.

| No. | Functional Group                             | Wavenumber (cm$^{-1}$) of samples at temperature |
|-----|---------------------------------------------|---------------------------------------------|
|     |                                             | 800 °C  | 850 °C  | 900 °C  |
| 1   | Si-O-Si bending                             | 470     | 470     | 467     |
| 2   | Si-O-Si symmetric stretching                | 806     | 805     | 805     |
| 3   | Si-O-Si asymmetric stretching               | 1102    | 1102    | 1100    |

Figure 3. The electrical impedance of the 800 °C ignition temperature treatment sample.

Figure 4. The electrical impedance of the 850 °C ignition temperature treatment sample.
Figure 5. The electrical impedance of the 800 °C ignition temperature treatment sample.

Figure 3, figure 4, and figure 5 shows that the frequency value was inversely proportional to the impedance value. The higher the frequency given to the sample caused a decrease in the impedance value. The effect of increasing the temperature of ignition also shows the higher impedance value, that is at the treatment temperature of 800 °C having an impedance between 0.033x10⁶ Ω to 16.043x10⁶ Ω, at a treatment temperature of 850 °C having impedances between 0.911x10⁶ Ω to 129.24x10⁶ Ω, and at a temperature treatment of 900 °C has an impedance between 0.907x10⁶ Ω to 188.54x10⁶ Ω. The higher the impedance value resulted higher the resistance of the electric current, so that it can indicate the ability of a material to conduct electricity. This study shows that the samples at the treatment temperature of 800 °C had the best electrical conductivity than other treatments. Therefore, the treatment can be used as a reference to make semiconductor materials from silicon with the basic ingredients extracted from rice straw biomass.

4. Conclusion

The extraction of silicon dioxide from rice straw using a modified method in previous studies was successfully carried out. Based on functional group analysis and electrical impedance properties of silicon dioxide rice straw samples, the best result was obtained at 800 °C ignition temperature treatment.

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