UTILIZATION OF SOYBEAN DREGS FOR SOLID FUEL PRODUCTION THROUGH HYDROTHERMAL CARBONIZATION

by

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Original scientific paper
https://doi.org/10.2298/TSCI200216292P

Hydrothermal carbonization is a thermochemical process used in converting biomass into a coal-like substance known as hydrochar. This is usually carried out at high temperature with water below the saturation pressure for a certain period known as holding time. The biomass used was soybean dregs, which is the residue obtained from processing soy sauce with low economic value. The aim of this study therefore, was to determine the calorific value of the hydrochar produced from soybean dregs at hydrothermal carbonization temperatures of 160 °C, 190 °C, and 220 °C and at holding times of 30 and 60 minutes, also at a temperature of 190 °C with the biomass and water ratio at 1:4 and 1:5. The results showed that the highest calorific value was produced a temperature of 220 °C and a holding time of 60 minutes, which was 3.866 kcal/kg, the highest carbon content was 26.49%, the lowest moisture content was at 1.77%, the lowest volatile content was at 62.98%, while the lowest ash content was 8.64%. Considering biomass to water ratio with the holding time, the highest calorific value was at 3.546 kcal/kg, the highest carbon content was 20.32%, the lowest moisture content at 1.71%, the lowest volatile content was 68.58%, while the lowest ash content was at 8.37%. The highest calorific value of the hydrochar produced was similar to the calorific value standard of lignite coal which is around 3511-4611 kcal/kg according to the American standard testing and mineral.

Key words*: hydrothermal carbonization, soybean dregs, soy sauce, calorific value, temperature, holding time*

Introduction

Coal is the second largest source of fossil energy in Indonesia after petroleum and natural gas [1]. It was reported that the demand for coal energy in the country from 2010-2015 was 6.2% [2] and could rise to 11% by 2050. This is largely because of the rapid development of coal-based industries such as cement, textile, and paper, as well as increase in the use of coal for the fuel of coal-fired power plants. The increase in the demand of energy also has a corresponding increase in the production of coal which also has effect on the its reserves. With this trend, it is predicted that the reserves will run out within 68 years [1].

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The government issued the Presidential Regulation No. 22 of 2017 concerning the National Energy General Plan, as a form of follow-up in achieving independence and security in national energy. According to the regulation, maximizing the use of new and renewable energy is one of the priorities in developing energy in Indonesia. This new energy is derived from RES including biomass [3]. These biological materials are made from plants or animals which are used in producing heat, power, fuels or as a substitute for fossil-based materials [4-6]. The energy potential of biomass is 32654 MW, this is the accumulation of biomass waste in Indonesia. However, its utilization is still very low, which is at 1626 MW [7]. The common ones are in the form of plants, trees, grasses, sweet potatoes, agricultural and forest wastes, feces, including animal manure. Biomass whose primary product has been removed, has a low economic value, however, it has the potential to be used as fuels [4-6].

One of the biomass with low economic value commonly found in Indonesia is the soybean dregs obtainable as a residue from the processing of soy sauce. Based on the value of production, about 3715014 kg of soy sauce was produced in Indonesia in 2015 [8], and a soy sauce gives about 59.7% of soybean dregs [9]. This soybean or soy sauce is readily available at a relatively cheap price, which makes available for the production of animal feeds at all times. However, one of the major ways of increasing its economic value is by processing it into alternative solid fuels [6].

Therefore, the aim of this study is to utilize soybean dregs (soy sauce) as an alternative solid fuel through hydrothermal carbonization (HTC). In addition, the calorific value of the hydrochar produced will be determined and subjected to proximate analysis in order to find out its quality.

One of the methods used in processing biomass into ready-to-use energy, which is environmentally friendly, is the HTC. This is a thermochemical process which converts waste at a high temperature and pressure, usually in a vacuum condition, into energy [6, 10]. Water is used as a solvent as well as a catalyst in the process [11] and this increases the hydrolysis reaction during the HTC process, thereby making the wet biomass need no pre-drying before being used in the process [12]. The main product from the HTC process is known as hydrochar. This is a carbon-rich solid with chemical characteristics similar to that of coal [13].

Also, HTC is a thermochemical conversion process which could be applied to various non-traditional substances such as organic fractions from urban solid waste, wet agricultural residues, sewage sludge, alga, and aquaculture residues. During the process, biomass is subjected to dehydration, decarboxylation, and decarboxylation reactions [14]. Some of the parameters in HTC process are: temperature, biomass type, holding time, pressure, and catalyst, all these vary depending on the type of solid fuels to be produced [15]. In general, increase in temperature, as well holding time, leads to decrease in moisture content. Previous studies showed that the best result of HTC was conducted with olive mill wastewater and based these studies, the water content decreased from 70% to below 30% [16]. Other studies have also shown that increase in reaction temperature and holding time during HTC, increase the carbon content [17].

Experimental method

This study uses soybean dregs as a biomass, it is still in a wet condition. Soybean dregs weighed 200 g, which was then added with water in a weight ratio of 1:4 and 1:5. The HTC parameters used in this study include: temperatures of 160 °C (lowest), 190 °C, and 220 °C (highest), holding times of 30 and 60 minutes and the ratios of biomass to water 1:4 and 1:5 at a temperature of 190 °C. The maximum capacity of the reactor engine used is 1200 liters. The process then produced steam and mixture of liquid with the hydrochar. The steam was condensed and used as liquid organic fertilizer while the mixture of liquid with hydrochar was separated through filtration process. The separated liquid, known as wastewater is also utilized as liquid organic fertilizer. Then, the wet hydrochar was dried in an oven, which is used as an alternative solid fuel briquette. The whole process is shown in fig. 1.

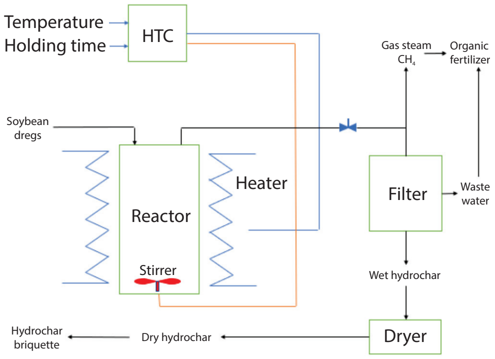

Figure 1. Research design scheme

The calorific value of the non-HTC dry raw materials and the hydrochar samples produced were determined and also subjected to proximate analysis. The ASTM[*] D5865 was used for the calorific value testing, ASTM D-3173 used for moisture content testing, the test involving its volatile matter used ISO 562, while ASTM D3174 was used for the tests involving the ash and carbon contents.

Result and discussion

Calorific value

According to fig. 2, the hydrochar produced at temperature of 220 °C and holding time of 60 minutes, has the highest calorific value, which was 3866 kcal/kg. The increase in temperature and holding time resulted in increase in pressure of the reactor. This high pressure solidifies the substance thereby reducing its moisture content especially within the pores. Low moisture content increases the calorific value of the fuel, as well as its efficiency and performance during combustion process [18].

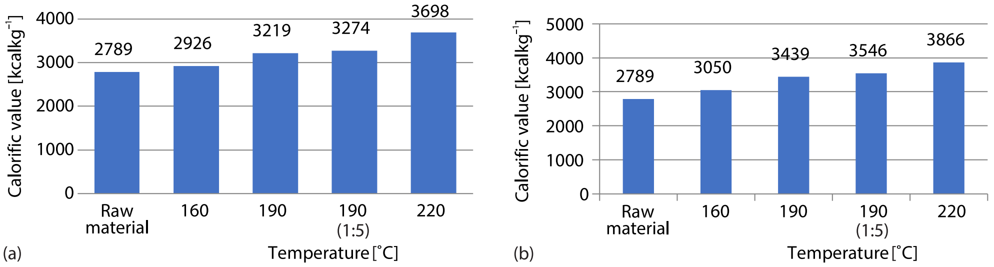

Figure 2. Calorific value; (a) holding time 30 minutes and (b) holding time 60 minutes

Considering fig. 2, the HTC parameter with biomass to water ratio of 1:5 at a holding time of 60 minutes resulted in the hydrochar with the highest calorific value which was at 3546 kcal/kg. The water used as the catalyst dissolved the biomass into a solute [6, 15], and the more the water added at a temperature of 190 °C, the greater the pressure, which then eases the solidification process of the material and reduces the moisture content, thereby increasing its calorific value. Also, the more the holding time, the more effective the hydrolysis and biomass decomposition processes [15].

The calorific value of the hydrochar produced at a temperature of 220 °C and a holding time of 60 minutes was 3866 kcal/kg. However, with biomass to water ratio of 1:5 at a holding time of 60 minutes, the hydrochar produced has a calorific value of 3546 kcal/kg which is equivalent to Lignite A coal (ASTM) within 3511-4611 kcal/kg.

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[*] ASTM D5865 – ASTM D3286 (obs.) – Standard test methot for Gross calorific value of coal and coke

Moisture content

According to fig. 3, the hydrochar with the lowest moisture content at 1.77% was obtained at a temperature of 220 °C and a holding time of 30 minutes. Considering the theory of coal thermal decomposition, an increase in temperature leads to fractures in the coal structure, thereby giving out water as the initial product of the process [19]. Hence, the moisture content of the coal decreases with increase in temperature during the hydrothermal process.

More so, the moisture content of the hydrochar at a holding time of 60 minutes was higher compared with that of 30 minutes because of the difference in the initial conditions of the oven used during drying. This is also due to the less tight storage of the dry hydrochar samples, thereby allowing water from the atmosphere to get in contact with it.

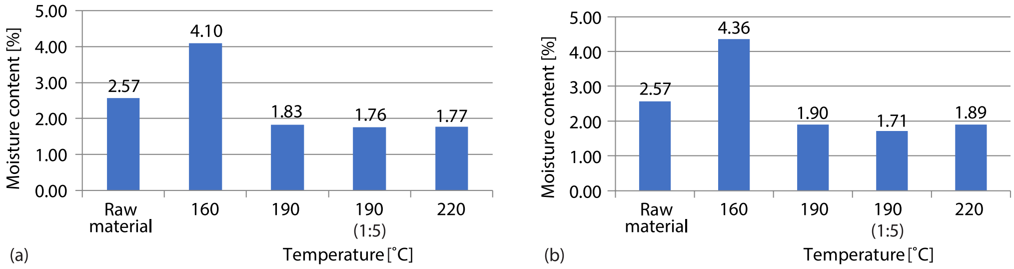

Figure 3. Moisture content; (a) holding time 30 minutes and (b) holding time 60 minutes

Considering fig. 3, the hydrochar produced at a ratio of 1:5 and a holding time of 60 minutes was with the lowest moisture content which was 1.71%. This is due to the fact that adding more water at a temperature of 190 °C results in more water vapor, which increases the biomass density. And the greater the density, the more difficult it is to be used as fuel [20]. However, increase in the holding time makes both the hydrolysis and biomass decomposition processes more effective [15].

Volatile matter

According to fig. 4, the hydrochar produced at a temperature of 220 °C and a holding time of 60 minutes has the lowest volatile content, which was at 62.98%. An increase in temperature reduces the volatile content of the hydrocarbon due to dehydration and decarboxylation reactions [21]. Also, an increase in temperature cuts off the molecular bonds or decomposes the compounds [19].

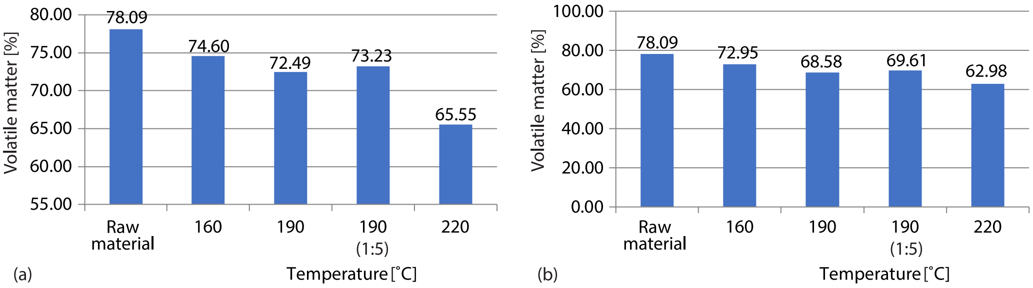

Figure 4. Volatile matter; (a) holding time 30 minutes and (b) holding time 60 minutes

Figure 4(b) shows that the hydrochar produced with the biomass to water ratio of 1:4 and at a holding time of 60 minutes, has the lowest volatile content which was 68.58%. The addition of more water at that particular temperature of 190 °C did not result in the complete decomposition of the carbon and H_2 compounds [22], hence, the volatile content was higher at ratio 1:5 than in ratio 1:4. Increasing the holding time makes the decomposition process of the compounds more efficient. High volatile content reduces the combustion efficiency of the hydrochar, thereby causing higher emissions [23]. In addition, increasing the holding time makes the hydrolysis and biomass decomposition processes more effective [15].

Ash content

Considering fig. 5(b), the hydrochar with the lowest ash content was produced at a temperature of 220 °C and a holding time of 60 minutes, which was 8.64%. This decrease in ash content was influenced by the decrease in moisture content, volatile matter, and the increase in fixed carbon [24].

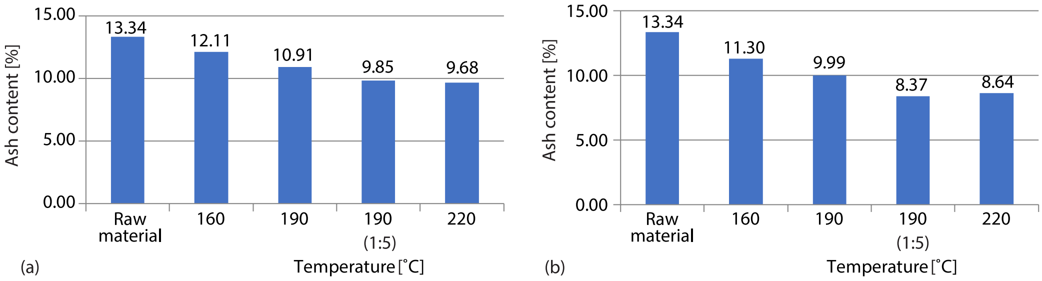

Figure 5. Ash content; (a) holding time 30 minutes and (b) holding time 60 minutes

According to fig. 5 (b), the hydrochar produced at biomass to water ratio of 1:5 and at a holding time of 60 minutes, has the lowest ash content, which was 8.37%. That was because the water used as a catalyst dissolved the biomass into a solute [19], and the more the water added at the temperature of 190 °C, the more the pressure generated, which helps its solidification process, thereby reducing the ash content. Increasing the holding time makes both the hydrolysis and biomass decomposition processes more effective [15].

Fixed carbon

According to fig. 6, the hydrochar with the highest carbon content was produced at temperature of 220 °C and at a holding time of 60 minutes, which was 26.49%. The carbon content of the hydrochar increases as the temperature increases, indicating that higher temperature increases the decomposition of biomass which does not react to become fragments and promote aromatization and re-polymerization reactions to produce hydrochar [11]. Also, an increase in the temperature reduces its volatile matter while increasing the carbon content and calorific

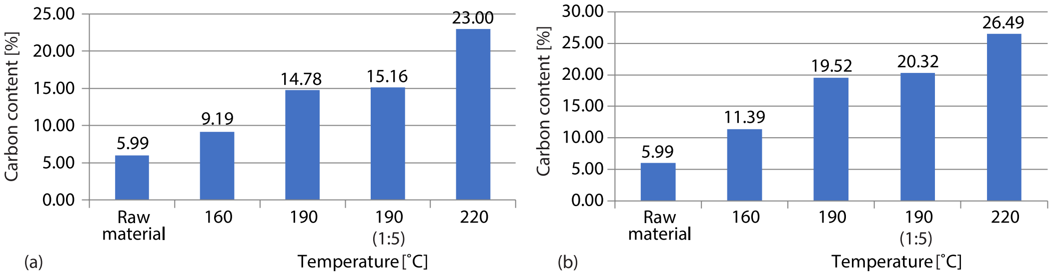

Figure 6. Carbon content; (a) holding time 30 minutes and (b) holding time 60 minutes

value, since both processes are influenced by hydrolysis reaction [17]. And the fixed carbon content is influenced by volatile matter, the higher the carbon content, the lower its volatile content [25]. More so, the carbon content is inversely proportional to the moisture content of hydrochar. The lower the moisture content, the higher the carbon content [19].

Figure 6 shows that the hydrochar produced at biomass to water ratio of 1:5 and at a holding time of 60 minutes, has the highest carbon content, which was 20.32%. This was because the water used as catalyst dissolved the biomass into a solute [19], and the more the water added at the temperature of 190 °C, the greater the pressure generated which helps the solidification process, thereby increasing its carbon content. Increasing the holding time makes the hydrolysis and biomass decomposition processes more effective [15].

Calorific value comparison

Table 1. Standard calorific value of coal according to ASTM [26]

Coal type	Calorific value [kcalkg^{-1}]
Anthracite	≥7777
Bituminous	5833-7777
Sub-bituminous	4611-5833
Lignite	3500-4611
Soybean dregs	**3866**
Peat	≤3500

Conclusion

The HTC is used to convert soybean dregs (soy sauce) into hydrochar with a calorific value similar to lignite coal. Based on results, temperature is the most influential parameter on the HTC process, which significantly increase the calorific value of the hydrochar. The biomass and water ratio were more influential on energy savings considering the fact that they produced hydrochar with calorific values closer to those of the preceding temperatures. The highest calorific value of hydrochar produced from the soybean dregs (soy sauce) was 3866 kcal/kg and this was at a temperature of 220 °C and at a holding time of 60 minutes. The calorific value of soybean dreg has been shown to increase through the HTC process and the hydrochar produced can be used as an alternative fuel to replace coal. This result is equivalent to the quality of Lignite A type of coal (ASTM) which is around 3511-4611 kcal/kg. This type of coal is widely used as a solid fuel for power plants. Lignite is young coal, dark brown in color, has a high water content of around 45%, and a high sulfur content. It is necessary to carry out further testing using the pressure parameter to determine the quality of the calorific and proximate values of hydrochar produced from the HTC process.

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Paper submitted: February 16, 2020
Paper revised: July 2, 2020
Paper accepted: September 20, 2020