Production of solid fuel by hydrothermal treatment using *Terminalia catappa* peels waste as renewable energy sources

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Abstract. The problem encountered in solid biofuels is their low quality, especially in terms of heating value. One treatment can improve this quality by employing a hydrothermal process. This study aims to determine the effect of a hydrothermal treatment of *Terminalia catappa* peels waste on the heating value and chemical composition. The experiment was conducted using temperature variations of 160°C and 220°C with holding times of 30 and 60 minutes. The water to biomass ratio used is 1:4. Furthermore, a heating value analysis and a proximate analysis was also conducted. The highest heating value is generated at a temperature variation of 220°C with a holding time of 60 minutes by 4,675.25 cal/gram. This value meets the Austrian solid fuel heating value standard (ONORM M 7135) i.e. ≥4,299.5 cal/gram. In the proximate analysis composition, the product showed a decrease in moisture content, ash content, and volatile matter, and an increase in fixed carbon along with an increasing temperature variation and its holding time. In this variation, the moisture content had reached 6.41%, with a volatile matter of 51.8%, an ash content of 2.2%, and a fixed carbon level of 39.59%. These results indicate a significant improvement in the quality of solid fuel. Therefore, hydrothermal treatment is able to answer the alternative fuels’ needs in regards to environmental friendliness.

1. Introduction
Energy demands are increasing rapidly in line with economic and population growth. Energy is used to power various life sectors. One sector that consumes significant energy is electricity. Until the end of 2015, the installed capacity of power plants in Indonesia reached 55,528 MW consisting of the Indonesian national power plant’s (PLN) production of 38,314 MW and non-PLN of 17,213 MW. When compared to the year 2014, which amounted to 53,065 MW, the installed capacity of power plants increased by 2,462 MW or 4.64% [1]. However, from that capacity, more than a tenth of the Indonesian population still do not enjoy electricity. This fact can be seen from the electrification percentage of 88.30% until the end of 2015. Therefore, the Indonesian government has launched a
35,000 MW project which is expected to be completed by 2019 to meet the people's electricity needs, which have increased rapidly in recent years. As the 35,000 MW project progresses, fuel requirements will increase significantly. The most rapidly increasing type of fuel is coal from fossil fuels. This is due to about 75% of the total additional electricity supply in the form of a Steam Power Plant (PLTU) which uses coal as its fuel [2]. The transfer of energy sources from fossil to renewable energy is urgent for Indonesia’s future economic development. On the other hand, the potential for renewable energy in Indonesia is currently not being fully utilized. The diminishing fossil energy reserve conditions should be anticipated by increasing efforts to diversify and conserve energy early [3]. The use of fossil energy also leads to the issue of greenhouse gases that add to the effects of global warming.

Biomass energy is more environmentally friendly compared to fossil fuels. Solid fuel from biomass can replace coal as a fuel for steam power plants. The energy generated has been used for various purposes for household needs, in the agricultural dryer and timber industries, and in power plants in the wood and sugar industries [4]. More modern usage that can be applied to various sectors is still not being applied to its current potential. Utilization of biomass into solid fuel has a lot of potential. One of the biomasses that can be used as an alternative to fossil fuel is T. catappa peels waste. The T. catappa tree was recommended by the Indonesian Ministry of Forestry as a greening crop of the city [5]. T. catappa has an important role in absorbing carbon dioxide (CO$_2$) and producing oxygen (O$_2$) in the process of photosynthesis. Therefore, T. catappa grows in many areas as a Green Open Space Filler (RTH) plant. However, the waste from falling fruit has not been utilized. Thus, the fruit waste becomes rotten and pollutes the city. T. catappa is an indigenous plant and spreads in almost all regions of Southeast Asia. It is also grown in several other countries such as Australia, India, and the southern USA. Most studies focus on the use of leaves and seeds as cosmetics and foodstuffs [6].

One way to utilize T. catappa peels waste is to process it into solid fuel using hydrothermal technology. Hydrothermal technology is efficient enough to significantly increase the heating value of biomass. Hydrothermal Treatment (HT) is a pressurized thermal conversion process with a water-saturated medium conducted at a relatively low temperature of 160-230°C [7]. In addition to requiring no initial drying, hydrothermal technology operates at the lowest temperature compared to pyrolysis and gasification [8,9]. Cheap and environmentally friendly alternative fuels are expected to meet these needs so that energy-self-sufficient communities can be realized. When compared with another thermal conversion processes, the energy required for the hydrothermal process is the lowest [10]. High-humidity biomass does not require initial drying prior to being processed since the initial drying process reduces most of the energy that must be maximized through the hydrothermal process. Significant hydrothermal advantages for converting biomass are the relatively low working temperature of each process, high energy conversion efficiency, and avoiding uneven drying of materials. Hydrothermal treatment (HT) converts solid waste with high moisture content to dry solid fuels, powder form, and high energy density. This source of nutrients can be used for organic fertilizer while hydrochar can be used as a coal-quality solid fuel equivalent [11-13]. Therefore, this paper focuses on the hydrothermal processing of T. catappa peels waste as a solid fuel to meet the needs of environmentally friendly alternative fuels.

2. Experimental Methods
The data was collected by direct experimentation with T. catappa peels waste using hydrothermal technology. After that treatment, the material undergoes the drying process and produces solid fuel. The resulting solid fuel will then have its heating value tested using a calorimeter bomb. To know the ash content, moisture content, volatile matter, and fixed carbon, we then conducted a proximate analysis. Data collection methods used in this study is the method of measurement. This experiment was exams using the ASTM standard (American Society for Testing Material). Heating value tests and proximate analyses were also conducted on dried raw material to determine the effect of hydrothermal treatment. Temperature variations are used at temperatures of 160°C and 220°C at the
lowest and highest, respectively. The holding time for each temperature is 30 and 60 minutes. The hydrothermal processing of *T. catappa* peels waste can be seen in Fig. 1.

![Diagram showing the hydrothermal process](image)

**Figure 1.** *T. catappa* Hydrothermal process

Fig. 1 shows that *T. catappa* tree as a Green Open Filler tree in various regions of Indonesia is fruitful and produces pollutants in the form of urban waste. *T. catappa* peels contain much lignocellulose. It has the potential to be processed into solid fuel. As described in Fig. 1, first, the water and *T. catappa* peels waste have been cut into small pieces and inserted into the reactor. The hydrothermal engine is equipped with an agitator connected to an electric motor to stir the mixture of biomass and water. After the hydrothermal process is complete, the vapor is removed along with a mixture of liquid and hydrochar. Then the liquid and hydrochar mixture is filtered. The vapor released can be adapted for use as a fertilizer, as can liquid that has been separated with hydrochar. After that, hydrochar is dried in order to become a solid fuel of quality.

3. Result and Discussion

3.1. Dried raw material

This research data was taken from each dry hydrochar sample of *T. catappa* peels waste which underwent hydrothermal treatment with variations in temperature and holding time. Heating value tests and proximate analyses were also carried out on dried raw material to learn the hydrothermal treatment’s effect on solid fuel quality. Raw heated material cannot dry out evenly. Dried raw material has more water content on the inside, while the outside has been burned. The weight of raw material after division became 57 grams, from an initial weight of 200 grams.

3.2. Hydrothermal products

Fig. 2 (a) shows that hydrochar produced from a hydrothermal process with a temperature of 160°C and a holding time of 30 minutes is brownish, and the coarse grain of *T. catappa* peels has not been destroyed. Fig. 2 (b) shows that hydrochar generated from the hydrothermal process with a temperature of 160°C and a holding time 60 minutes is darker than the experimental result of a temperature variation of 160°C with holding time of 60 minutes, and the coarse grain of *T. catappa* can decompose, although it cannot yet be powdered.
Figure 2. *T. catappa* hydrochar (a) T160°C 30 minutes, (b) T160°C 60 minutes, (c) T220°C 30 minutes, (d) T220°C 30 minutes

Fig. 2 (c) showed that hydrochar produced from hydrothermal processing at a temperature of 220°C with a holding time of 30 minutes is dark brown and powdery with a coarse texture. Some crude fiber is still not destroyed, even in a minimal amount. Fig. 2 (d) shows that hydrochar produced from hydrothermal processing at a temperature of 220°C with a holding time of 60 minutes takes form as a powder and is evenly distributed and black.

### 3.3. Heating value and proximate analysis result

The heating value test is done using a bomb calorimeter, yarn, and nickel. The sample consists of five variations, including: dried raw material with a hydrothermal sample temperature of 160°C with holding time 30 minutes, temperature 160°C with holding time 60 minutes, temperature 220°C with holding time 30 minutes, and temperature 220°C with holding time 60 minutes. After testing the heating value, further proximate analysis was performed. Data obtained from the proximate analysis includes: ash content, water content, volatile matter, and fixed carbon. All these figures are presented in Table 1.

Table 1. Proximate analysis and heating value results

|                  | Moisture content (%) | Volatile matter (%) | Ash (%) | Fixed carbon (%) | Heating value (cal/gram) |
|------------------|----------------------|---------------------|---------|-----------------|--------------------------|
| Raw material     | 8.71                 | 66.95               | 5.98    | 18.34           | 3,371.45                 |
| HT 160°C 30 minutes | 8.51                | 63.22               | 3.56    | 24.69           | 3,579.06                 |
| HT 160°C 60 minutes | 7.98                | 62.45               | 2.89    | 26.66           | 3,756.13                 |
| HT 220°C 30 minutes | 6.68                | 54.16               | 2.66    | 36.48           | 4,367.85                 |
| HT 220°C 60 minutes | 6.40                | 51.80               | 2.20    | 39.58           | 4,675.25                 |

Table 1 shows that the highest heating value in this study was obtained at a temperature variation of 220°C with a holding time of 60 minutes, which is 4,675.25 cal/gram, while the lowest heating value in raw material amounted to 3,371.45 cal/gram. The process increased the average heating value of each calorie by 7%. The heating value itself is a standard measure of energy in fuel, especially solid fuels. The heating value is analogous to the amount of heat obtained when a fuel mass burns
completely and the product is cooled to 298 K [14]. To be used, the heating value must meet certain standards. The heating value of a hydrothermal temperature of 220°C with holding time of 60 minutes exceeds the Austrian standard for solid fuel (ONORM M 7135) i.e. ≥4,299.5 cal/gram [15]. This shows that the result of the hydrothermally processed waste of *T. catappa* peels is feasible to be used.

![Figure 3](image.png)

**Figure 3.** Proximate analysis graphics

Fig. 3 (a) shows that the highest moisture content in this research is obtained from the raw material, and is equal to 8.71%. Reduction of moisture content along with temperature rise and holding time length are significant to the solid fuel result. Solid fuel quality is strongly influenced by moisture content—the lower the moisture content, the better fuel quality [16].

The hydrothermal product at temperature 220°C meet moisture content standards of Austrian (<10) [15], Germany (<12) [15], American (<8) [17], and French (<15) [18]. Fig. 3 (b) shows that the highest level of volatility in this research is obtained from the raw material, and is equal to 66.95%. Solid fuel with high volumes of moisture can remove most of the heating value it has as a combustion vapor.

Fig. 3 (c) shows that the higher the temperature and holding time in the hydrothermal treatment, the more the ash decreases. The ash drop in this experiment averaged 4%. The higher ash also indicates a lower heating value in solid fuel and vice versa. On the other hand, ash is also an impurity of solid fuel. The hydrothermal treated ash meets the standard solid fuel content of France (<6) [17]. Fig. 3 (d) shows that the fixed carbon here increased significantly with increasing temperature variation and holding time.
4. Conclusion
In conclusion, the analysis results show that a hydrothermal product treated at a temperature of 220°C with a holding time of 60 minutes has the highest heating value, at 4,675.26 cal/gram. The heating value of solid fuels through hydrothermal treatment complies with the solid fuel heating value standards of Austria (ONORM M 7135) i.e. ≥4,299.5 cal/gram. Along with increasing temperature variation and holding time of HT, there is a decrease in moisture content, ash, and volatile matter, and an increase in the solid fixed carbon of fuels. These results indicate a significant improvement in solid fuel quality. Thus, hydrothermal technology deserves to be used as an alternative utilization of biomass waste into solid fuel.

5. References
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