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Analysis of the effect of temperature and raw material mixes on the pyrolysis process with single retort-rocket stove technology on the characteristics of sawdust charcoal briquettes

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ABSTRACT

Government-subsidized LPG gas as household fuel for the poor is increasingly scarce. The discourse to return to using traditional fuels emerged because one of the biomass wastes, namely wood processing in the form of sawdust produced by small and medium industries, can be used to replace LPG gas. This study aims to determine the effect of peak temperature and sawdust mixture on making charcoal briquettes with Single Retort-Rocket Stove Pyrolysis Technology. This technology is one of the alternative pyrolysis technology used for self-heating. This technology is cleaner because the smoke can help speed up combustion to be more energy-efficient. The Rocket Stove system allows spreading of heat from the bottom to the top of the reactor. The raw material for use from Mahogany and Sonokeling Sawdust. Both types of sawdust combine with different ratios. Completely Randomized Design (CRD) non-factorial methods showed that all treatments, namely the ratio of sawdust mixtures and the temperature settings used, greatly influenced the proximate value obtained, where all experiments were very significantly different because $F_{calculate}$ > F_{table} (0.05). The best briquette proximate results were found in an optimum mixture of rosewood and mahogany with a ratio of 70:30 at 350°C with a setting time of 1 hour, which is close to the SNI 01-6235 standard, with respective characteristic values, namely: 5.5% moisture content; ash content 5.3%; bonded carbon 66.2%; volatile matter content of 22.8% and a caloric value of 6470 cal/gr.

INTRODUCTION

Wood is a natural product that has an essential role in human life. Wood can use as a supporter of the primary needs of society in general. Based on the facts in the field, of 100% volume of logs, only 66% is sawn timber. The remaining 34% has become wood chips and sawdust. Sawdust is often considered a waste that cannot be reused. The powder can be processed by printing through certain process stages. One way is to use a briquette printer with a horizontal or vertical press system. Mahogany and Sonokeling are the types of wood most widely planted in production forests and are often used to make furniture, thus directly producing sawdust, which has little benefit. So the two types of sawdust waste for use as research material. Wood is also used as a supporting tool in making houses (poles, frames, doors, windows, etc.). Wood products and furniture that produce sawdust waste that accumulates cause environmental problems [1], [2], but behind the shortage of wood processing waste, used for several purposes that can be of economic value. For example, the use of bark waste is for fuel or energy [3], [4], wood chips and sawdust produced from wood can be used as charcoal briquettes or activated carbon [5]. Briquette is an alternative material that can replace fuel [6], [7], especially for rural communities as domestic fuels as well as home-scale industrial users' fuel [8], [9]. One of the briquette making materials is waste from the wood processing industry in the form of powder [10]. After going through the briquette process, the following process is making charcoal, charcoal wood briquette charcoal made by carbonization. In the process of burning briquettes, it will cause a reaction reactant, which is thermal decomposition, and gives rise to heat as a result of the dissolution of various molecules. At temperatures of 275 degrees Celsius, cellulosic lingo briquettes begin to release H2O and CO2 gas. Besides that, charcoal and methane are also formed[11], [12]. Carbonization temperature will significantly affect the charcoal produced, so determining the right temperature will determine the quality of charcoal [13]. Briquette is an alternative material that can replace fuel, especially for rural communities as domestic fuel and household-scale industries that use fuel [3], [7], [11]. In general, the calorific value of firewood is not always a significant indicator of whether or not the wood used as fuel, but the most important is being environmentally friendly [6], [14], [15].

Central Java Province is one area that has a forest area and waters that are not large enough, which is 774,000 Ha, which ranks 27 out of a total of 34 provinces in Indonesia. However, this province is the most productive in forest resources management, including various types of wood used to make different types of finished products. Correspondingly, many companies have made briquette charcoal factories from sawdust waste [16]. The use of wood powder charcoal briquettes from Indonesia, aside from being cheap, also has proximate values (moisture content, volatile matter content, ash content, carbon content) and heating value that meets international standards. The problem is the optimum mixture of sawdust used to make charcoal briquettes that meet export standards relating to the quality of charcoal briquettes, where the carbonization temperature will significantly affect the charcoal produced. The carbonization process generally uses two methods, namely, internal combustion and external combustion [17]. The internal combustion method is a commonly used conventional technique that uses heat from its raw material, which burns so that some of the raw material will become fuel and ash. This process requires a processing time of around 2-3 days, producing smoke that pollutes the environment. The method of combustion from the outside of the raw material is entered into the pyrolysis reactor and then given heat from outside by burning using fuel. This method produces more charcoal yield because very little is turned to ash. The authoring process is relatively faster than the internal combustion technique. Still, this technique requires a lot of fuel during the process, which means using natural resources and requires a higher cost. The smoke produced can be controlled so that it does not pollute too much [18][19][20].

Furthermore, Carbonization temperature will determine the charcoal produced, so identifying the right temperature will determine the charcoal [21]. Other research conducted in manufacturing wood powder briquettes mixed with used oil and clay can increase the heating value of briquette charcoal, which is 11,064.26 kcal/kg, and the ash content of 10.45% [22]. However, this method can increase the ash content of the briquettes, so it does not comply with the briquette charcoal standards set. The mixture of sawdust and kempas wood with starch has a calorific value of 7,358 kcal / kg at a charcoal temperature of 550˚C with ash content of 2.69% [23], but adding starch does not increase the efficiency of the charcoal briquettes because the production value briquettes will be high. After all, starch is one of the ingredients of food mixing.

Research on the calorific value in sonokeling and mahogany wood found that the water content of sonokeling charcoal is 13,12%, and the calorific value is 2.290 cal/gr. The mahogany wood charcoal has a water content of 13,37% and a calorific value of 2.992 cal/gr [24]. Using a pyrolysis rocket stove, a mixture of the two types of wood powder, sonokeling and mahogany, can increase calorific values and reduce briquettes' water content. Single Retort rocket stove pyrolysis is also an indirect combustion system through the combustion chamber contained in this reactor. This combustion system was chosen because the heat source produced is at the center of the reactor; besides that, the rocket stove system has been proven to produce fuel efficiency and high heat. Combining a single pyrolysis retort with a rocket stove will provide better pyrolysis process performance. This method uses fuel from outside, which is burned in the rocket stove combustion chamber as a starter until the raw material in pyrolysis produces pyrolysis gas that burns. After the pyrolysis gas is produced, the gas is flowed into the rocket stove combustion chamber and burned to heat and carried out the pyrolysis process to completion. This process is considered semi-auto thermal because it uses some of the pyrolysis raw material energy in the form of pyrolysis gas for the rest of the process. The rocket stove pyrolysis method combines internal and external combustion methods, so this method can overcome the shortcomings of the external combustion method, which results in less yield, a long process, and produces smoke. This method can also overcome the shortcomings of internal combustion methods that require relatively sizeable outside energy.

METHOD

This experimental study aimed to find the best composition using a Completely Randomized Design (CRD) non-factorial method, namely a mixture of mahogany and rosewood sawdust with a ratio of 70:30 has a higher calorific value than the other compositions. The combination of sawdust briquettes produced has high calorific value, and the raw materials are easy to obtain and safe for the environment. The study was conducted based on a data set consisting of the dependent variable: moisture content, moisture content, ash content, fixed carbon, calorific value and the independent variable, charcoal temperature and sawdust (mahogany, sonokeling) to be optimized. These two types of powders are most common in every furniture production site in Central Java. Dependent variable: ash content, moisture content, volatile matter, carbon content, and charcoal calorific value (As per the proximate standard set).

1. Design and Experiment Method

Briquette is obtained through several stages [25], which are sawdust mixed and dried beforehand to get a maximum moisture content value of 13-15 percent, which can be done by using a rotary dryer or using a source of solar heat. The dried sawdust is put into the briquette extrude machine.

The carbonization process is carried out using pyrolysis at temperatures of 350° C and 500° C for 1 hour. The technology used is Single Retort with external combustion, where a heat source is supplied to the pyrolysis retort center. This concept is similar to the Rocket stove gasification system, so the heat obtained is higher than the pyrolysis system by burning from below. With this system, the heat efficiency for pyrolysis is higher, which results in a faster and more complete combining process. This technology is different from pyrolysis, generally where the retort heated from below.

2. Moisture Content

Moisture content can affect the quality of charcoal briquettes. The lower the water content, the higher the heating value, and combustion power [26]. Charcoal can absorb vast amounts of water from the air around it. The ability to absorb water influences surface areas and pores

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of the charcoal and the carbon content attached to the briquette. Thus, the smaller the carbon content is bound to the charcoal briquettes, the more significant the charcoal briquettes' ability to absorb water from the surrounding air [27].

3. Volatile Matter

Volatile compounds are substances that can evaporate as a result of the decomposition of compounds in charcoal other than water. The high vapor content in charcoal briquettes will cause more smoke when the briquette turn on, caused by a reaction between carbon monoxide (CO) [6], [27].

4. Ash Content

Ash is the remaining part of the combustion process that no longer has the carbon element. The central aspect of ash is silica, and its influence is not right on the heating value produced. The higher the ash content, the lower the quality of the briquettes. Because of the high ash content can reduce the heating value of charcoal briquettes [27], [28].

5. Carbon Content

The carbon content in charcoal briquettes influences on ash content and volatile compound levels. The carbon content will be high if the ash content is low, and the volatile decomposition level is low. Good charcoal briquettes are charcoal that has a high carbon content [21], [27].

6. Statistical Analysis

Completely Randomized Design (CRD) non-factorial method non factorial used for statistical analysis on this experiment. Ten experiments were conducted in this study (refer to Table 1), and each trial was taken three times after the average take it. Combining the two types of powder as a briquette is assumed to have the same mass of 1000 grams.

$$Y_{ij} = \mu + T_i + \epsilon_{ij}, \tag{1}$$

Table 1. Experimental design

No	**Sawdust Material**	**Ratio**	**Temperature (°C)**
1	Mahoni	30	350
	Sonokeling	70	
2	Mahoni	40	350
	Sonokeling	60	
3	Mahoni	50	350
	Sonokeling	50	
4	Mahoni	70	350
	Sonokeling	30	
5	Mahoni	60	500
	Sonokeling	40	
6	Mahoni	30	500
	Sonokeling	70	
7	Mahoni	40	500
	Sonokeling	60	
8	Mahoni	50	500
	Sonokeling	50	
9	Mahoni	70	500
	Sonokeling	30	
10	Mahoni	60	500
	Sonokeling	40	

RESULTS AND DISCUSSION

1. Moisture Content

Moisture content is a physical property contained in an object or material that provides information on the amount of water in the elements. According to SNI, 01-6235-2000 states that the maximum moisture content of charcoal briquettes is 8%.

The research results showed the best water content in treatment 1, with a value of 4.18% for an hour of the carbonization process at 350°C with a ratio of 300 gr of mahogany wood powder and sonokeling 700 gr (30:70). The temperature of the carbonization process affects the porosity of a charcoal product [6], [26], [29], [30]. Besides, the powder mixture also affects the water content obtained but does not show a significant difference. Based on the regression test, the effect of setting the temperature on the moisture content of raw materials tends to be linear, where the higher the temperature and the longer the setting time, the lower the water content [31]. The analysis results by the non-factorial CRD method obtained a mixture of powder and charcoal temperature, when the value of Fcalculate > Ftable (129,1 > 5,99), it is very significantly different moisture content for each observed from the mixed sawdust and temperature.

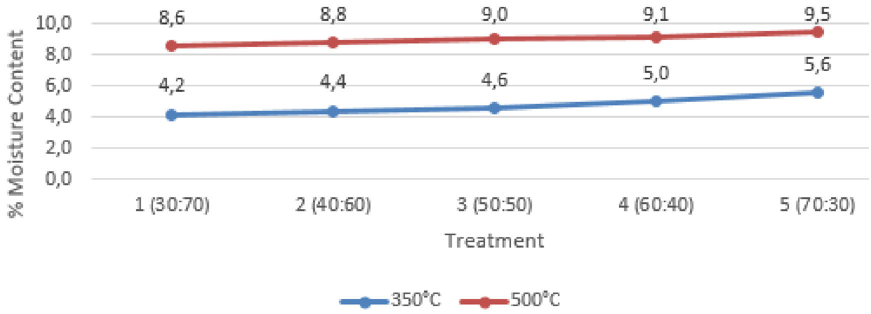

Figure 1. Correlation between treatment and temperature to the acquisition of 350°C and 500°C moisture content

2. Volatile Matter

Volatile matter is a chemical reaction between carbon monoxide and alcohol derivatives that occurs, causing smoke to burn charcoal [30]. Volatile matter obtained by the smallest mixture of mahogany wood charcoal and sonokeling charcoal briquettes was 7.1% in the 10th treatment with a composition of the wood powder ratio of 70:30 at 500°C. While the largest has obtained in the form of the sawdust ratio of 30:70 at temperatures 350°C with a percentage of 33.1%.

From the results of statistical analysis, Fcalculate > Ftable (2190,72 > 5,99); it is very significantly different volatile matter for each observed from the mixture sawdust and temperature, the higher the combustion temperature and the mixture of ratios between mahogany sawdust and sonokeling (30:70) obtained lower volatile matter [32], [33].

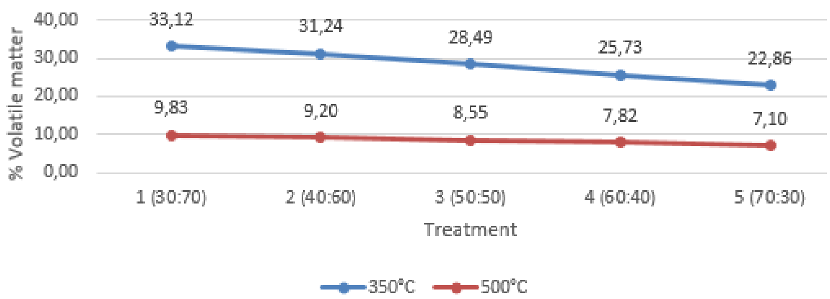

Figure 2. Correlation between treatment and temperature to the acquisition of 350°C and 500°C Volatile matter

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3. Ash Content

The ash of wood sawdust charcoal briquettes is a chemical reaction that occurs because the charcoal burning process has carried out. The amount of ash obtained is influenced by ash, protein fiber, fat and carbohydrate [6], [28]. In the mixture of mahogany and sonokeling wood powder briquettes, the lowest ash content has obtained at treatment 5 (70:30) at 350°C and the highest at treatment 1 (30:70) at 500°C.

The statistical analysis results found $F_{calculate}$ > F_{table}, where F_{table} α 0,01 and 0,05 from temperature 350°C & 500°C had different with F calculate values are 129,19 and 229,16. Those very significantly other ash content for each observes from the mixture of sawdust and temperature.

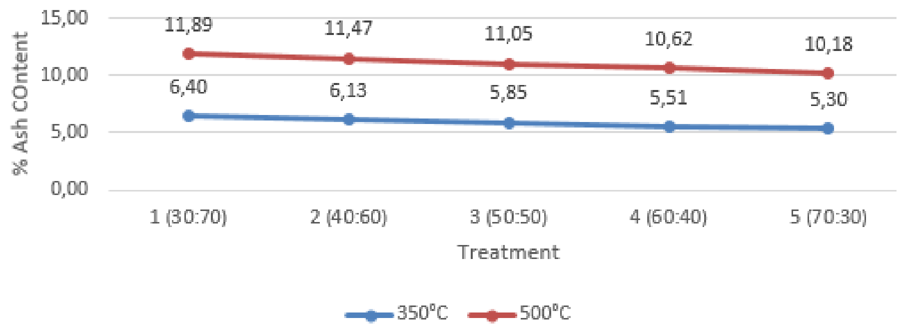

Figure 3. Correlation between treatment and temperature to the acquisition of 350°C and 500°C ash content

4. Fixed Carbon

The carbon content of sawdust briquettes mixed with mahogany and sonokeling obtained varies. The mixture of mahogany (70%) and sonokeling (30%) each received a high carbon content, at a temperature of 500°C obtained a carbon content of 73%, while at a temperature of 350°C a 66% carbon content was retrieved. In this study, where the results were in line with those of others, the carbon content got correlated with temperature [6], [7]. Where the higher the temperature used for combustion, the higher the carbon content obtained.

Analysis statistical from this observes with CRD non factorial method had found F calculate > F table (294,6 > 5,99); where is every each Fcal very significantly different with alphas.

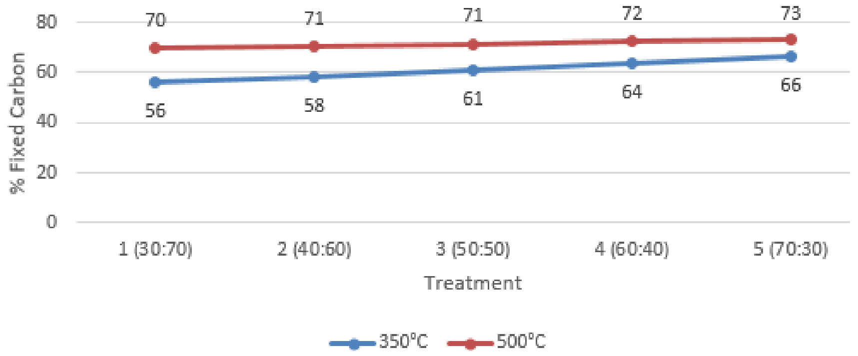

Figure 4. Correlation between treatment and temperature to the acquisition of 350°C and 500°C fixed carbon

5. Calorific Value

In general, the heating value of charcoal influences the combustion temperature, the higher the combustion temperature, the higher the heating value obtained [21], [28], [31]. In this study, the average combustion temperature of 350°C has a heating value of 6,186 cal/gr, while at a temperature of 500°C, it has an average of 6,961 cal/gr. Besides, the material or sawdust composition also affects the heating value of charcoal. The mixture of mahogany and sonokeling powder with a ratio of 70:30 has a higher heating value than other forms. Anova statistics show $F_{calculate} > F_{table}$ (19,48 > 5,99); the calorific value significantly differs from the mixed sawdust and temperature.

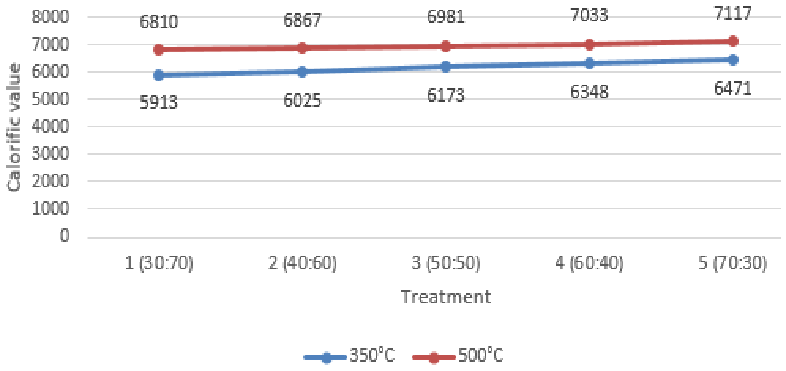

Figure 5. Correlation between treatment and temperature to the acquisition of 350°C and 500°C calorific value

CONCLUSION

Each type of sawdust has different chemical properties. Wood sawdust has chemical properties that meet the quality of briquettes, which can use as fuel. From the research results, in addition to the variable temperature variation charcoal, the Mahogany and Sonokeling Sawdust ratio is very influential on the entire proximate test conducted. Figure 6 shows that when the combustion temperature is 350°C, the value that does not meet the SNI standard for charcoal briquettes is the level of volatile matter and carbon bound. In contrast, the heating value obtained in all experiments exceeds the established SNI standard for the whole experiment. The statistical test results using the non-factorial CRD method showed that all treatments, namely the ratio of the mixture of sawdust and the curing temperature used in this study, greatly influenced the proximate value obtained.

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