Chapter 14
Briquette Combustion Characteristics of *Cerbera Manghas* Leaves with Rejected Pineapple as Binding Agent as a Sustainable Fuel

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Abstract Litter from fallen leaves of the *Cerbera manghas* plant is commonly found throughout Indonesia. Various studies have shown that briquettes formed from the falling leaves of *Cerbera manghas* may be able to reduce waste and be used as a new energy source. However, previous studies employed tapioca as a binding agent for briquettes, which is an edible starch, and their use as a binder competes with the availability of food resources. Alternatively, rejected pineapple would be used as a binding agent to remedy the problem since it is not edible and reduces unused waste. The briquette was subsequently researched to determine the optimal production parameters as well as its potential as a sustainable fuel. The 95% to 5% ratio of biomass to briquette is used to achieve a high calorific value of 4338.79 kcal/kg while maintaining the structure of the briquette in check. The usage of this briquette is supported by both the calorific value test and ultimate analyses. According to the research on the four combustion characteristics (ignition time, burning temperature, combustion rate, and burning time), the composition that gives the best briquette is obtained by using a particle size of 60 mesh and compressed by the hydraulic pressure of 2 MPa.

Keywords Biomass · Briquette · Inedible · *Cerbera manghas* · Pineapple waste

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14.1 Introduction

The world's energy demand has continuously increased year by year, and with it, the supply of fossil fuels will only keep diminishing more each year (Pambudi et al. 2017). Fossil fuels are also non-renewable and not environmentally friendly (Kotcher et al. 2019). Therefore, another form of energy must be introduced in order to keep up with the ever-increasing energy demand, one of them being renewable energy from biomass. Not only does biomass energy have the potential to replace fossil fuels, but it is also more environmentally friendly than fossil fuels as it has the potential to be carbon neutral (Tian and You 2019). Furthermore, it is available from a wide range of sources such as animal waste and civil waste (Bot et al. 2022). One of the ways to utilize these biomasses as a source of energy is through direct combustion (Thipkhunthod et al. 2005). However, burning these biomasses directly without processing them is not advisable as they have a lot of moisture content which hinders combustion performance. Furthermore, due to their low bulk density, it is hard and expensive to transport (Sengar et al. 2012). All of these shortcomings can be overcome by processing them into briquettes as they have lower moisture content and higher bulk density, hence making them easier to transport while also having better combustion properties (Mwampamba et al. 2013; Stolarski et al. 2013; Sakkampang and Wongwuttanasatian 2014). Furthermore, there is a net positive gain of energy from converting biomass to briquettes. Briquettes are also socially beneficial as they enable people living in rural areas to get additional income and are a great energy source (Bot et al. 2022). Nevertheless, since there is a wide range of biomass selections originating from plant or fruit wastes (Brunerová et al. 2017) with differing properties, each of these biomasses must be studied separately to determine its performance as a briquette (Bilgili et al. 2017).

A certain study in Indonesia has determined the possibility of forming briquettes from *Cerbera manghas* leaves (Anggono et al. 2016). The leaves of the *Cerbera manghas* tree are usually considered waste because they don't have a practical use and form waste that is burned most of the time. Burning these leaves wastes valuable energy resources that could otherwise be used, and at the same time contributes to the production of greenhouse gases. Previous studies (Anggono et al. 2016, 2017, 2018) have also shown that converting waste leaves into a more compact type of briquettes rather than simply burning them improves the fuel quality of the leaves. Moreover, a previous study (Anggono et al. 2016) showed that briquettes made from the leaves of *Cerbera manghas* have a calorific value comparable to other briquettes.

Previous studies (Anggono et al. 2016, 2017, 2018) have solved the main problem of waste disposal by converting leaves into briquettes, but there are also drawbacks. In these studies, tapioca flour was used as a binding agent for briquettes. Tapioca is an edible source that competes with the availability of food resources when also used for making briquette (Lewandowski 2015; Girotto et al. 2015). With the prevalence of food waste and food shortages in some areas today, using food resources to make briquettes is not recommended. Therefore, alternatives to tapioca flour for use as briquette binders must be considered and researched to maintain the availability of the resource food.

Rejected pineapple has the potential to change tapioca as a binding agent because it contains natural fibers and sugars. These rejected pineapples originated from pineapples that have been screened but are classified as unsellable due to poor. Furthermore, they are often separated from the edible fruit and left to rot, resulting in unsightly and inedible waste. This waste can be reduced by using it as a binder for briquette. In fact, one study (Anggono et al. 2020) found the feasibility of discarded pineapple as a binder replacement for tapioca flour with superior quality compared to other common briquettes, suggesting that discarded pineapple is also a good tapioca substitute.

The aim of the current study is to determine the impact and feasibility of substituting discarded pineapple for tapioca as a binder for renewable energy sources. This study thoroughly inspects the quality of briquettes using bomb calorimeters, final analysis, and combustion characteristics testing. To measure the change in calorific value with the use of tapioca compared to pineapples sorted with different ratios of biomass and binder, a test using a bomb calorimeter is performed. Calorific value tests and a final analysis of briquettes were conducted to determine their practical usability. Combustion property tests were conducted to determine the ideal production settings for *Cerbera manghas* leaves from *Cerbera manghas* tree as shown in Fig. 14.1, briquettes, and pineapple waste as shown in Fig. 14.2.

Fig. 14.1 *Cerbera manghas* tree

Fig. 14.2 Rejected pineapple

14.2 Experimental Method

The raw materials for the briquettes, *Cerbera manghas* leaves and discarded pineapples, were easily collected as most of them were considered waste. After collecting them, the *Cerbera manghas* leaves were dried in the sun for a week to reduce their moisture content. After sufficient exposure to sunlight, the leaves were torn into small pieces with various biomass sizes as shown in Fig. 14.3. The pineapple was then crushed into a viscous material, as shown in Fig. 14.4. Combining the crushed leaves with the crushed pineapple acts as a binding agent and is placed in a mold as shown in Fig. 14.5. Compress into briquettes under hydraulic pressure using the press shown in Fig. 14.6.

The first inspection of the briquettes was a bomb calorimeter test using a 1341 Plain Jacket Oxygen Bomb Calorimeter, as shown in Fig. 14.7. Briquettes undergo calorific value testing and final analysis according to ASTM standards. Finally, the combustion properties of briquettes were evaluated in terms of burning velocity, burning temperature, burning time, and ignition time. A final experiment was performed by varying the size of the biomass and the pressure used to condense the briquettes. The particle size of the biomass was altered for 20 mesh (800 μm), 40 mesh (425 μm), and 60 mesh (250 μm). The hydraulic pressure was set at 1 and 2 MPa. Various combinations of particle size and hydraulic pressure were investigated, and the combination that produced the best combustion characteristics was determined. The test was repeated three times and the results were averaged and found to be significant. The briquette results can be seen in Fig. 14.8.

Fig. 14.3 Shredded *Carbera manghas* leaves

Fig. 14.4 Smashed rejected pineapple

Fig. 14.5 Press mold

Fig. 14.6 Hydraulic press machine

14.3 Results and Discussion

The briquette in this study uses a 95 to 5% biomass-to-binder ratio as it provides a high calorific value while also keeping the rigidity of the briquette in check (Anggono et al. 2020; Gotama et al. 2021). The result of the calorific value test shows that the briquette has a calorific value of 4347.46 kcal kg^{-1} according to the ASTM D

Fig. 14.7 Oxygen bomb calorimeter

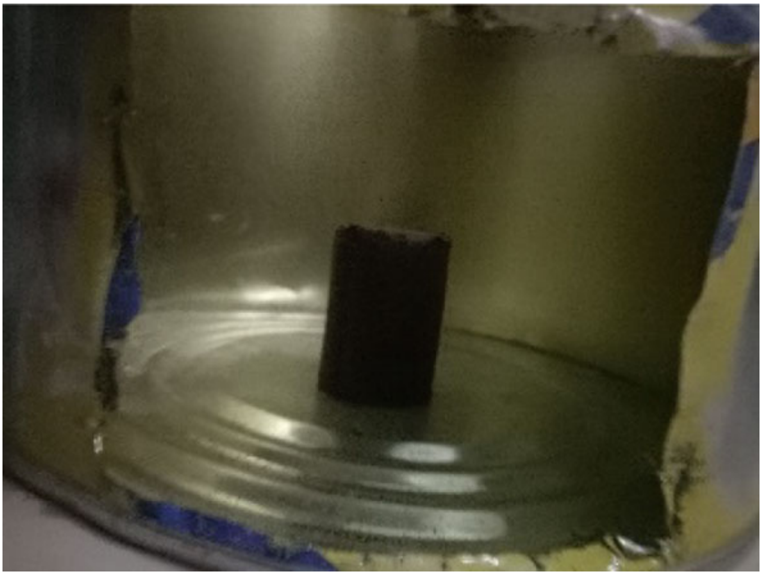

Fig. 14.8 Briquette made from *Cerbera manghas* leaves with rejected pineapple

5865—13 standards. The calorific value is comparable to other biomass briquettes mentioned in Table 14.1 (Anggono et al. 2016, 2017, 2018). Since tapioca has a higher caloric value (3574.47 kcal/kg) (Anggono et al. 2016), the tapioca-bonded briquette has a higher caloric value than the pineapple bonded briquette (435.02 kcal/kg). Table 14.2 shows the result of the ultimate analysis. The combined weight of the carbon and hydrogen contributes to the calorific value as they are the primary combustible elements.

The effects of different particle sizes and hydraulic pressure on the burning temperature are shown in Fig. 14.9a. The higher burning temperature the more it is desired because it gives higher heat transfer, which is achieved by using smaller particle size and higher compression pressure. The maximum burning temperature (547 °C) was found for a briquette with a compression pressure of 2 MPa and particle size of 60 mesh.

Figure 14.9b shows the effect of different particle sizes and hydraulic pressure on ignition time. Ignition time refers to the time it takes to ignite the briquette (Anggono et al. 2017). A longer ignition time may be achieved by having briquette of a smaller particle size and higher compression pressure. The peak ignition time (296 s) is observed for briquettes with a compression pressure of 2 MPa and particle size of 60 mesh.

Table 14.1 Comparison between 95% *Cerbera manghas* leave waste briquettes with 5% rejected pineapple to other briquettes

Biomass source	Binder	Biomass to binder ratio	Calorific value (kcal kg^{-1})
Cerbera manghas leaves	Rejected pineapple	95%:5%	4347.46
Cerbera manghas leaves (Anggono et al. 2016)	Tapioca	90%:10%	4164.00
Pterocarpus indicus leaves (Gotama et al. 2021)	Rejected pineapple	95%:5%	4169.76
Pterocarpus indicus leaves (Anggono et al. 2018)	Tapioca	90%:10%	4648

Table 14.2 95% *Cerbera manghas* leaves and 5% rejected pineapple briquette ultimate analysis

Parameters	Unit	As received	Test method
Carbon	[% wt]	43.85	ASTM D 5373–16
Hydrogen	[% wt]	5.12	ASTM D 5373–16
Nitrogen	[% wt]	2.93	ASTM D 5373–16
Oxygen	[% wt]	25.86	ASTM D 3176–15

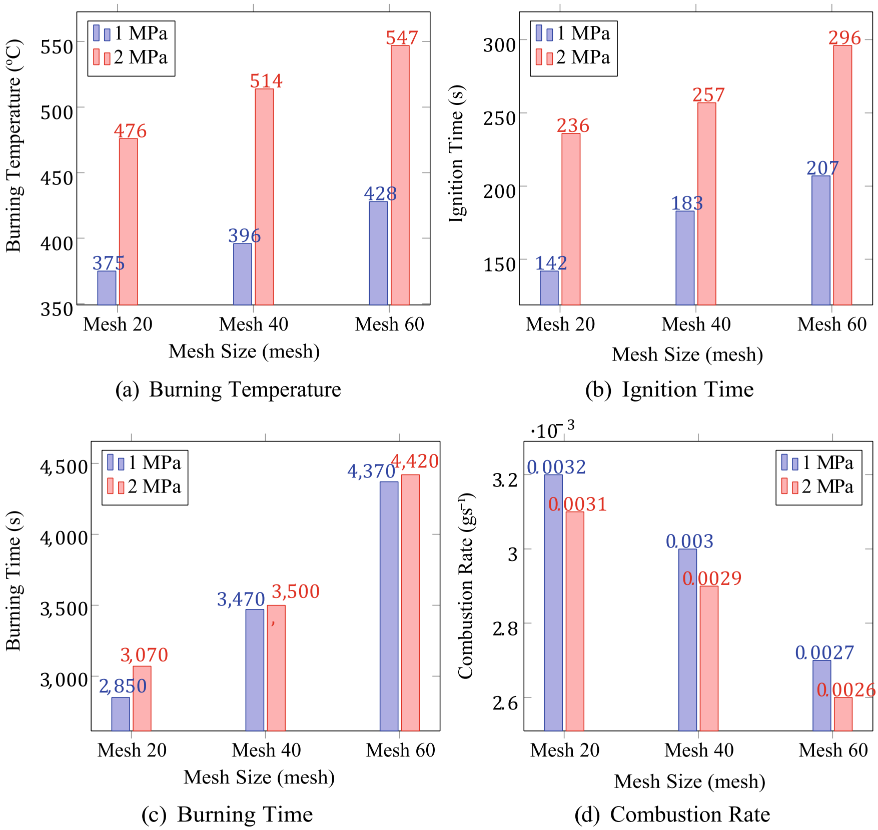

Fig. 14.9 *Cerbera manghas* leaves and rejected pineapple briquette combustion characteristics

The impact of various particle sizes and hydraulic pressures on the burning time is given in Fig. 14.9c. The burning time indicates the time required for the fuel to reduce into ashes after being ignited (Anggono et al. 2017). A long burning time can be achieved by a briquette with a smaller particle size and larger compressing pressure. Peak burning time (4420 s) was found in a briquette with 2 MPa compacting pressure and particle size of 60 mesh.

The effects of different particle sizes and hydraulic pressure on the combustion rate are shown in Fig. 14.9d. The combustion rate shows how fast the combustible components of the fuel are consumed when the briquette is burned (Anggono et al. 2017). A faster combustion rate results in a shorter burning duration. A slower combustion rate may be achieved with a smaller particle size and higher compacting pressure. The lowest combustion rate (0.0026 g s^{-1}) is observed for briquettes with a compression pressure of 2 MPa and a biomass size of 60 mesh.

There is no significant difference in the burning time and the combustion rate at different hydraulic pressure levels studied. However, these results are consistent with previous studies showing that greater hydraulic pressure resulted in longer burning duration and faster combustion rate (Anggono et al. 2017). As for burning temperature and ignition time, it shows that higher compacting pressure resulted in higher temperature and longer ignition duration of the briquette. This increased combustion performance can be attributed to the denser briquette produced with higher hydraulic pressure during fabrication. Denser briquettes have more fuel mass per unit volume, resulting in higher burning temperature from higher energy release compared to the less dense briquette. However, it also means that denser briquettes take more time to be ignited.

14.4 Conclusion

The results of this study suggested that 95% Cerbera manghas leave waste briquettes with 5% rejected pineapple give briquette with good structural integrity and a high calorific value of 4347.46 kcal kg^{-1}, which is comparable to other briquettes that use a 95 to 5% biomass to binder ratio. The use of rejected pineapple to replace tapioca as a binding agent has led to the reduction of the overall calorific value of the briquette. Nevertheless, the results of the calorific value and ultimate analysis tests show that the briquettes using *Cerbera manghas* leaves and rejected pineapples as briquette binders can be used as a renewable energy source. Combustion characteristics analysis suggests that the optimal production parameters for briquettes are 2 MPa hydraulic pressure and 60 mesh size or 250 μm particle size. These 2 parameters resulted in a briquette with a combustion rate of 0.0026 g s^{-1}, a burning temperature of 547 °C, a burning time of 4420 s, and an ignition time of 296 s.

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