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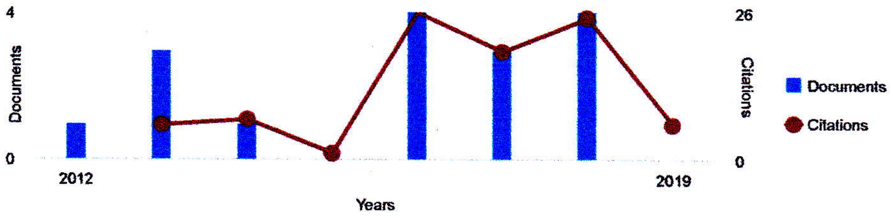

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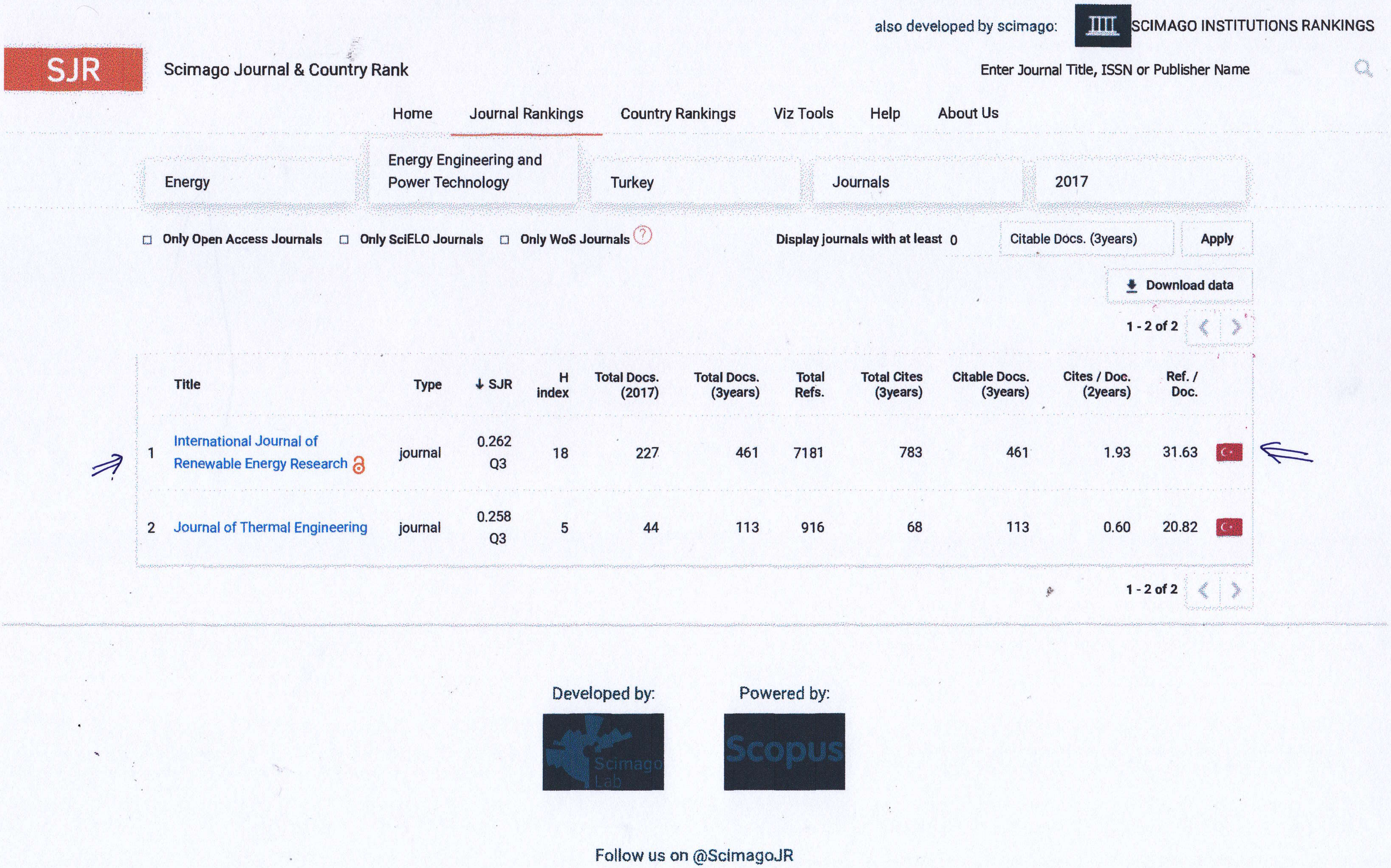

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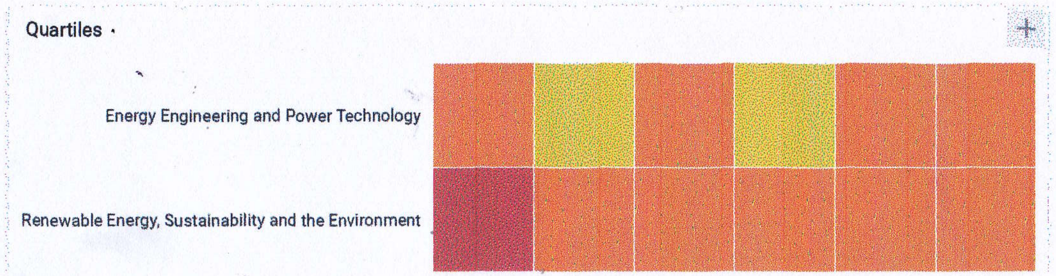

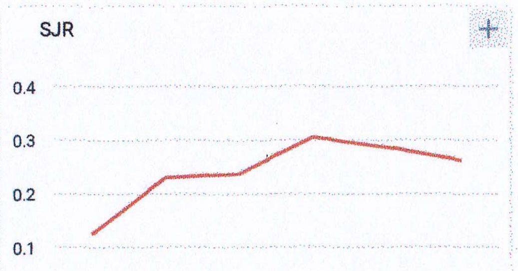

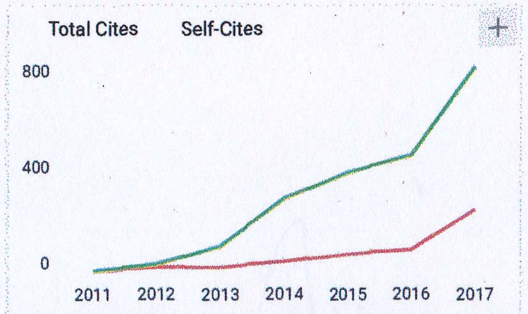

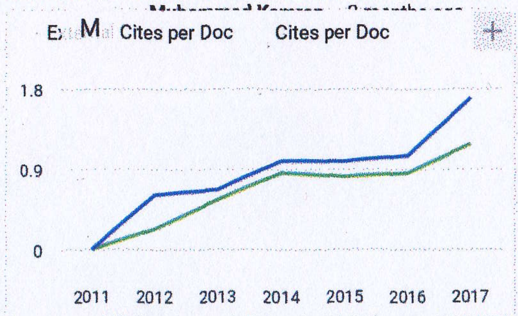

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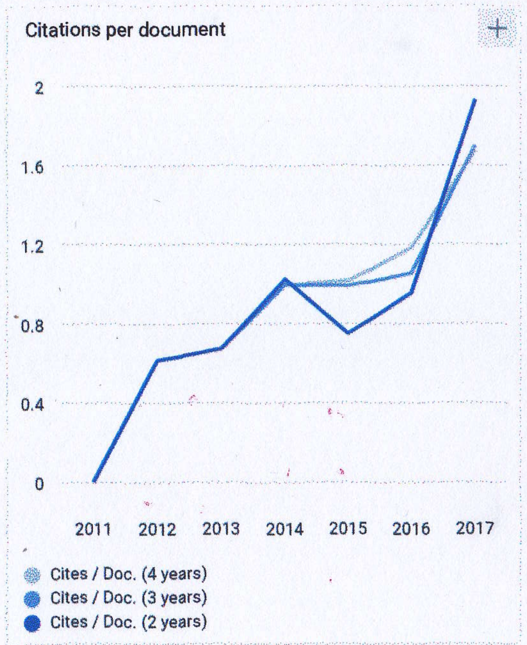

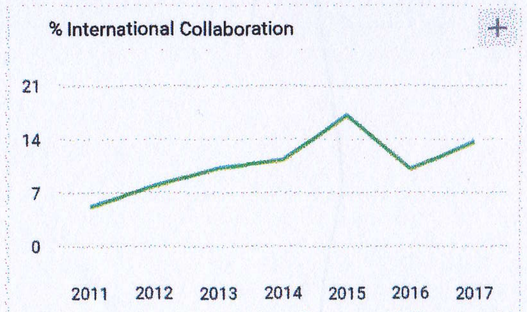

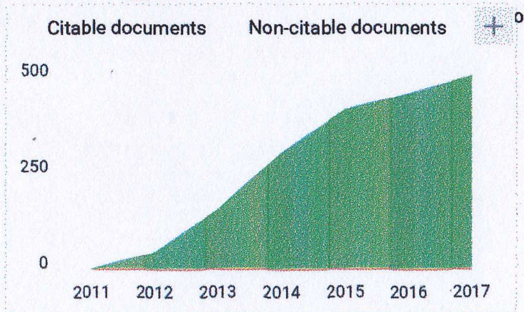

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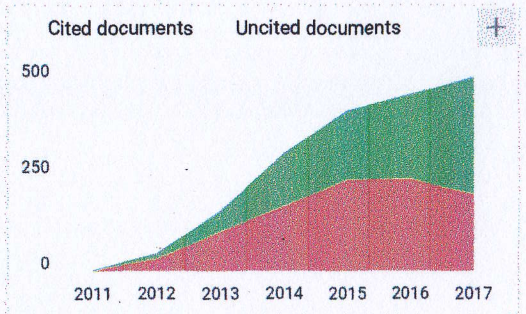

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International Journal of Renewable Energy Research-IJRER

Vol 8, No 3 (2018)

September

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INTERNATIONAL JOURNAL of RENEWABLE ENERGY RESEARCH
W. Anggono et al., Vol.8, No.3, September, 2018

Biomass Briquette Investigation from *Pterocarpus Indicus* Twigs Waste as an Alternative Renewable Energy

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Received: 20.02.2018 Accepted:02.05.2018

Abstract- *Pterocarpus indicus* are commonly utilized as greening and found in Surabaya city. Since this plant exists in large number, its fallen twigs become waste and aggravating the cleanliness of the Surabaya city. This study has investigated the possibility to utilize *Pterocarpus indicus* twigs waste as a renewable energy source. The study investigated the effect of tapioca (binding material) proportion toward the calorific value of briquette. The investigation was conducted using biomass composition ranges from 50% to 90% with 10% increase for each trial. The result suggests that the 90% biomass material - 10% binding materials blends are the ideal composition for *Pterocarpus indicus* twigs waste briquette. Afterward, proximate and ultimate analyses were conducted to determine the viability of *Pterocarpus indicus* twigs waste as fuel. Another investigation was also conducted to discover the effect of particle size and compacting pressure on briquette quality. The parameters used for assessing briquette quality include flame temperature, ignition time, burning time, and combustion rate. The result suggested that the value of flame temperature, ignition time and burning time increase with the increase of compacting pressure and smaller particle size. Combustion rate dropped as the pressure increase and particle size reduced. The best quality for briquettes of *Pterocarpus indicus* is acquired with a particle size of 60 mesh and compacting pressure of 2 MPa, which have a flame temperature of 515 °C, ignition time 251 seconds, burning time of 6590 seconds, and a combustion rate of 0.00303 gr/seconds.

Keywords *Pterocarpus indicus*, briquettes, biomass, renewable energy, green energy

1. Introduction

Demand for energy is currently on the rise in respond with the shortage of non-renewable fuel resources and increase in human population [1,2]. This reduction of non-renewable energy sources, imprudent exploitation of them coupled with higher demand for energy affects the market by increasing the price of fuel for the consumer. Subsequently, the sustainable energy sources are expected to meet the energy needs and balance the demand and supply of energy sources [3,4,5]. These sustainable energy sources come in many forms, including biomass [6].

Biomass can be defined as any form of organic material derived from living organism which is renewable and capable to be utilized as fuel. Biomass origins are classified into two major groups, natural and derived materials. Biomass is found in the form of wood and wood wastes, agriculture crops and wastes, urban solid waste, animal wastes, aquatic plants, algae, and industrial waste. Since the origins of biomass are obtainable from nature, biomass is available in large number and require small to no cost to obtain [7,8].

In term of production and usage, biomass has a wide range of production methods and utilization methods [9]. In term of pollution reduction, biomass has the potential to be CO_2 neutral since biomass is mainly derived from resources which reduce CO_2 concentration in air [7,10-12]. These features put biomass as an important asset for tackling the energy problem in modern society [13].

In utilizing biomass as useful products, two types of process are mainly used. These processes are known as thermo-chemical process and bio-chemical process. Thermo-chemical processes are processes conducted to convert biomass resources into products which are high in energy. Thermo-chemical processes include hydrogenation, pyrolysis, liquefaction, gasification, and combustion [1]. The bio-chemical process is a process to decompose biomass which contains carbohydrates into sugars and further into biofuels using catalyst and microorganism. The by-products of bio-chemical conversion include alcohols, chemical products, diesel, and gasoline [14].

To this day, the most common and oldest thermo-chemical process is direct combustion [15, 16]. Combustion is a process of chemical reaction which occured exothermically between fuel, oxygen and combuster [17]. Direct combustion works by directly burn the biomass and transform the chemical energy keep in biomass into electricity, heat or machine-driving power and many more. While combustion is one of the most common methods to utilize biomass, it comes with several disadvantages. Most of the time, biomass requires pre-treatment before igniting. Pre-treatment is required because the combustion process is only attainable with a moisture content of biomass lower than 50% and sometimes the biomass obtained has higher moisture content than 50% [1]. Additionally, biomass has low bulk density and thus requires more effort in handling biomass in large quantity. The difficulty in handling high quantities of biomass results in higher expenditure for handling, transporting and storing biomass [18,19].

In order to reduce these disadvantages of biomass such as high moisture content and low bulk density, biomass may be processed into briquette [18-20]. Briquette is a type of fuel created to increase the bulk density value of biomass and turn it into a fuel with higher energy density [20]. Briquette has better energy parameter, higher calorific value, higher density, lower moisture content and easier to use than its raw material [8,21]. In addition, briquetting (the process of creating briquette) prevents redundant handling of biomass derived from waste such as storing, burning and burying [20]. The process of creating briquette consist of drying, shredding, and pressing (compacting). While these additional processes for converting biomass into briquette require energy, the energy used to develop briquette was found to be lower than the energy obtained from utilizing briquette [22]. In Bangladesh, the utilization of briquette from rice husk waste has been proven as a financially viable solution towards the maintainable growth of forest resources [23]. In a social context, some studies have suggested that briquette is welcomed by society as alternative renewable energy and making it marketable. Briquetting stands as an important asset in providing an improvement to ecological environments, reducing energy shortages, and increasing people's income [24]. Studies also suggested that people are willing to change from charcoal to briquettes fuel as long as the price of briquettes is comparable with that of charcoal [25].

Since biomass may be acquired from wastes of plants, these wastes have potential to be used as biomass fuel resources [26]. Tropical countries with high varieties of floras produce an abundant number of biomass resources. Developing countries were also found to generate a high amount of biomass as well [7,27]. One of many countries that fit both descriptions is Indonesia. Indonesia is a tropical nation in developing state with a gamut of plant species across the country. Some of these plants produce waste which leads to abundant biomass waste in Indonesia [28]. In Surabaya, Indonesia for example, *Pterocarpus indicus* as shown in fig. 1 is a plant that is commonly found on the street and produce a high number of wastes. The twigs of this plant fall to the ground regularly in every season and causing litters in the street of Surabaya, as seen in fig.2. The abundance of these twigs waste produced by *Pterocarpus indicus* on the street may raise a question regarding Surabaya's city cleanliness. Furthermore, unnecessary handling of these wastes by burning causes not only additional GHG (greenhouse gases) production, which are commonly produced in energy and transportation sectors [29], but also wasting usable energy source. One method to solve this problem of *Pterocarpus indicus* twigs waste is by converting these twigs waste into briquettes.

Fig. 1. *Pterocarpus indicus* tree in Surabaya

Fig. 2. *Pterocarpus indicus* twigs and leaves waste in Surabaya

By converting these twigs waste into briquette, the number of twigs waste in Surabaya will be reduced. Furthermore, the efficient utilization of these twigs waste may reduce GHG production from unnecessary burning of twigs waste. In order to maximize the potential of briquette derived from *Pterocarpus indicus* twigs waste, investigations of *Pterocarpus indicus* twigs waste need to be conducted. The investigations may result in optimizing the quality of manufactured briquette and further increase its effectiveness as a solution [2,30-33].

2. Experimental Method

The first process of creating briquette is drying the biomass which is used as briquette raw material. In this study, drying was conducted by gathering the wastes that fall from *Pterocarpus indicus* trees and exposing them to sunlight for three days. After sun-dried, the next step is to shred the material into desired proportions. After shredded into a suitable size, the shredded biomass was mixed with tapioca flour as to bind the biomass. Finally, the biomass and tapioca flour combination were compacted by putting them under a certain pressure in the die to mold them into a cylindrical shape. The finished briquettes were then tested to determine the optimum particle size and compacting pressure. An example of finished briquettes is shown in fig. 3.

Fig. 3. *Pterocarpus indicus* twigs waste biomass briquette

In the investigation for the proportion of biomass to tapioca, the proportion is varied from 50% biomass-50% tapioca to 90% biomass-10% tapioca with an increase of 10% for biomass proportion. The calorific value estimation was performed using 1341 Plain Coat oxygen bomb calorimeter. The result of this investigation showed the effect of biomass to tapioca proportion in determining the calorific value of briquette.

Pterocarpus indicus twigs waste briquette were also examined for its proximate and ultimate analyses. Proximate and ultimate analyses have been used in briquette investigations to help predict the condition when the briquette is utilized as fuel [34-37]. These analyses are the straightforward fuel characterization method which is easily performed in conventional or state-of-the-art laboratories [38]. The result of proximate analysis gives information such as moisture content and volatile matter which are important when discussing the viability of fuel's utilization in society [34]. Some studies have suggested that proximate analysis results can predict the calorific value of product [38-40]. The result of ultimate analysis provides information regarding the important elemental composition of *Pterocarpus indicus* twigs waste briquette including carbon, hydrogen, nitrogen, sulfur, and oxygen. All of these tests were performed under ASTM standards.

For investigating the effect of particle size, three types of particle size were used. These three types of particle size consisted of 20 mesh (size of 800 μm), 40 mesh (size of 425 μm), and 60 mesh (size of 250 μm). The particle sizes were obtained by grinding the biomass in wire mesh. The size of wire mesh determined the particle size obtained for briquette raw material. These three types of particle size differences were studied to determine the ideal briquette particle size in terms of physical strength and burning feature. Fig. 4 displays the result of processing the biomass into three different particle sizes.

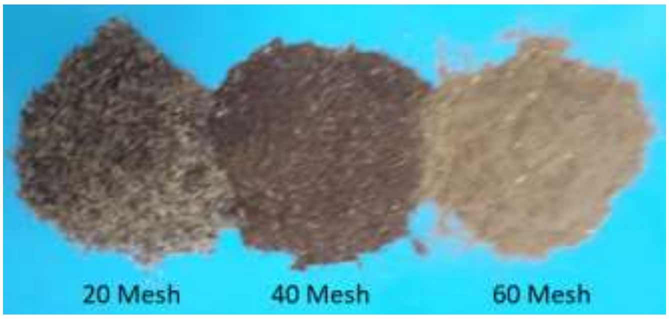


Fig. 4. Particle size variation of *Pterocarpus indicus* twigs waste biomass

Another parameter tested is the pressure used in compacting the briquette. The pressure variations used in this study are 1 MPa and 2 MPa. A higher magnitude of pressure caused the briquette to break and unable to retain its form. All of these pressure variations for compacting briquette were used in each type of particle size of shredded *Pterocarpus indicus* twigs waste. A hydraulic machine was used to apply pressure for compacting briquettes. The pressure was applied to a die with a diameter of 25 mm to shape the briquette. The shape of the die can be seen in fig. 5.

Fig. 5. Briquettes die and mold

In determining the quality of briquette as a function of particle size and pressure, four parameters of burning characteristics were used. These four characteristics include flame temperature, ignition time, burning time, and combustion rate. Flame temperature is the temperature measured in the surface of briquettes during combustion. Infrared thermometer and thermocouples were utilized as measuring device to determine the flame temperature.

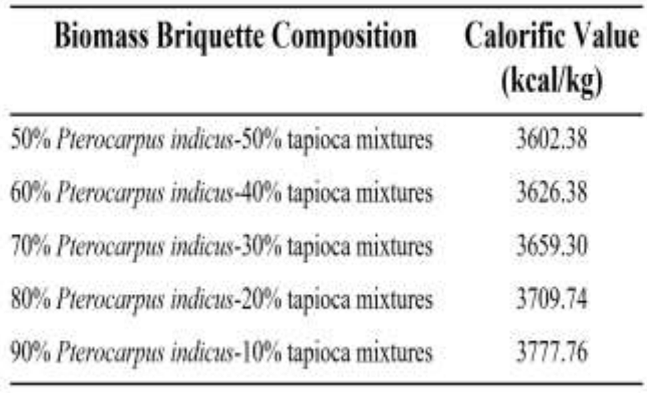
Ignition time is a parameter which measures the time required for briquette to combust continuously from the start of ignition. Burning time is the time required for briquettes to reduce into ashes. Both ignition time and burning time were measured using a stopwatch. Combustion rate is the speed required for the change of mass to occur in briquette.

Most of the methodologies used in this study are similar to most briquette investigations' procedures [34,35,41-43]. However, some studies have suggested that different species of biomass significantly affect the quality of briquette and its combustion properties [44-46]. Since no study has been conducted to analyze the potential of *Pterocarpus indicus* twigs waste as briquette, the results of this study merit the novelty of discovering it.

3. Results and Discussion

The effect of proportion between *Pterocarpus indicus* twigs waste to tapioca for briquette calorific value is shown in table 1. A graph that shows the change of calorific value in respond with the percentage of *Pterocarpus indicus* twigs waste is shown in figure 6. The investigation result indicates a strong relationship between briquette composition with a calorific value of briquette. A higher percentage of *Pterocarpus indicus* twigs waste in briquette yields higher briquette calorific value. The biomass-binder relationship toward calorific value discovered in this study is similar with the result of the study conducted by Thabuot et al and Willyanto et al [2,35]. From the investigation, it was found that 90% biomass and 10% tapioca mixtures yields the highest calorific value. This finding is also in line with the calorific value of its respective materials. 100% *Pterocarpus indicus* twigs waste has calorific value of 3860.39 kcal.kg and 100% tapioca flour has a calorific value of 3574.47 kcal/kg. Since tapioca has smaller calorific value than *Pterocarpus indicus* twigs waste, the more tapioca added in briquette composition, the lower the heating value of briquette produced. Although 100% *Pterocarpus indicus* twigs waste has higher calorific value than 90% twigs waste and 10% tapioca mixtures briquette, pure *Pterocarpus indicus* twigs waste briquette will not be able to hold its form.

Table 1. *Pterocarpus indicus* twigs waste biomass briquette calorific value at various composition



Biomass Briquette Composition	Calorific Value (kcal/kg)
50% *Pterocarpus indicus*-50% tapioca mixtures	3602.38
60% *Pterocarpus indicus*-40% tapioca mixtures	3626.38
70% *Pterocarpus indicus*-30% tapioca mixtures	3659.30
80% *Pterocarpus indicus*-20% tapioca mixtures	3709.74
90% *Pterocarpus indicus*-10% tapioca mixtures	3777.76

The good news of this finding is the economic advantage it gives. Since *Pterocarpus indicus* twigs waste can be obtained with almost no cost, the only expenditure for obtaining the material for this briquette is from tapioca mixtures. The lower is the tapioca as binding material needed, the lower is the cost of producing *Pterocarpus indicus* twigs waste briquette.

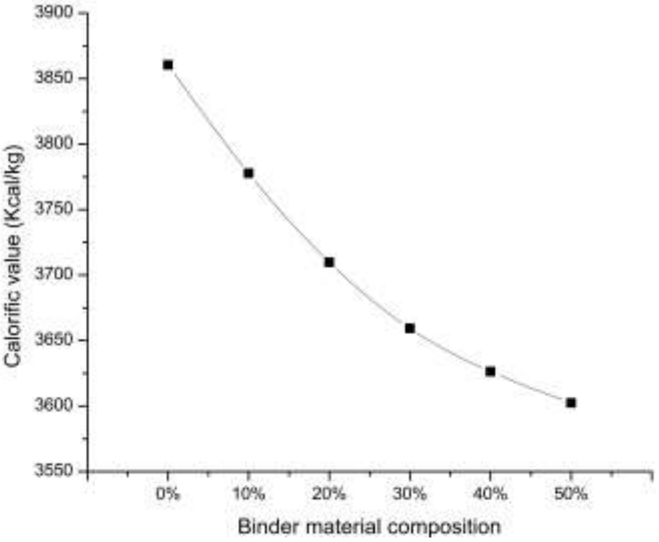


Fig. 6. Effect of binder material to the calorific value *Pterocarpus indicus* twigs waste briquette

Pterocarpus indicus twigs waste briquette analyses result for both proximate and ultimate have been conducted. These analyses were performed on the best proportion of *Pterocarpus indicus* twigs waste and tapioca mixture. Table 2 shows the test result for proximate analysis. The total moisture content of *Pterocarpus indicus* twigs waste briquette was found to be 9.8 %wt, which is less than 50% and thus indicate its capabilities to be combusted [1]. The fixed carbon value shows the range of non-volatile matter in *Pterocarpus indicus* twigs waste briquette. The higher the value of fixed carbon, the harder it is to burn the product. The volatile matter value shows the capability of a material to be burned. The higher is the value of volatile matter, the less effort is needed to ignite the product. Since *Pterocarpus indicus* twigs waste briquette has higher volatile matter (67.9 %wt) than fixed carbon value (12.2 %wt), it can be inferred that *Pterocarpus indicus* twigs waste briquette is easy to burn. The value of ash content indicates the vestigial product after combustion. The higher the value of ash content, the bigger is the ash remain found after the combustion process. The desired value for ash content is to be as small as possible [2,47].

The result of ultimate analysis for *Pterocarpus indicus* twigs waste briquette is shown in table 3. The carbon content in *Pterocarpus indicus* twigs waste briquette was found to be 41.55%wt and the element of hydrogen was found to be 4.76 %wt. The higher the percentage of carbon and hydrogen in the product, the higher its energy content [39]. The value of nitrogen and sulfur obtained from ultimate analysis affect the by-products of combustion. The result of burning nitrogen and sulfur produce NO_x and SO_x which are highly hazardous for human respiratory. The total content of nitrogen and sulfur in *Pterocarpus indicus* twigs waste briquette were found to be less than 1 %wt (0.45 %wt) and can be considered safe [48]. Some empirical formulas have suggested that the effect of oxygen content can either be positive or negative in determining the calorific value of the fuel. However, these formulas show that the effect of oxygen content on calorific value is small compared to carbon and hydrogen elements [39].

Table 2. Proximate analysis result of *Pterocarpus indicus* twigs waste and tapioca mixture

Test Method	Parameters	Unit	Value
ASTM D 2961-11	Total Moisture	%wt	9.8
ASTM D 3172-13	Fixed Carbon	%wt	12.2
ASTM D 3174-12	Ash Content	%wt	10.1
ASTM D 3175-11	Volatile Matter	%wt	67.9
ASTM D 4239-14E1	Total Sulfur	%wt	0.17
ASTM D 5865-13	Gross Calorific Value	kcal/kg	3777

Table 3. Ultimate analysis result of *Pterocarpus indicus* twigs waste and tapioca mixture

Test Method	Parameters	Unit	Value
ASTM D 5373-14	Carbon	%wt	41.55
ASTM D 5373-14	Hydrogen	%wt	4.76
ASTM D 5373-14	Nitrogen	%wt	0.28
ASTM D 4239-14E1	Sulphur	%wt	0.17
ASTM D 5373-15	Oxygen	%wt	33.37

The pressure and particle size effect on briquette combustion characteristic have been examined. Their effect of these variables on the flame temperature of *Pterocarpus indicus* twigs waste briquette is shown in fig. 7. Fig. 7 shows that the finer the size of shredded biomass, the higher is the flame temperature obtained. The higher magnitude of pressure shows an increase in flame temperature as well. The relation of these parameters to flame temperature are in line with the previous study conducted with *Cerbera manghas* leaf waste as briquette's raw material [2]. The highest flame temperature (515 °C) is acquired with *Pterocarpus indicus* twigs waste briquette produced using a particle size of 60 mesh and compacting pressure of 2 MPa.

Figure 8 displayed the influence of particle size and compacting pressure on ignition time of *Pterocarpus indicus* twigs waste briquette. The result indicates the positive relationship between particle size and pressure to ignition time. The finer the particle size of biomass in briquette and the pressure used to form briquette, the longer the time needed for ignition. This finding is similar to studies conducted by Al-Malah et al and Davies et al [41,42]. From this result, it can be seen that the highest ignition time (251 seconds) is obtained from *Pterocarpus indicus* twigs waste briquette produced using a particle size of 60 mesh and compacting pressure of 2 MPa.

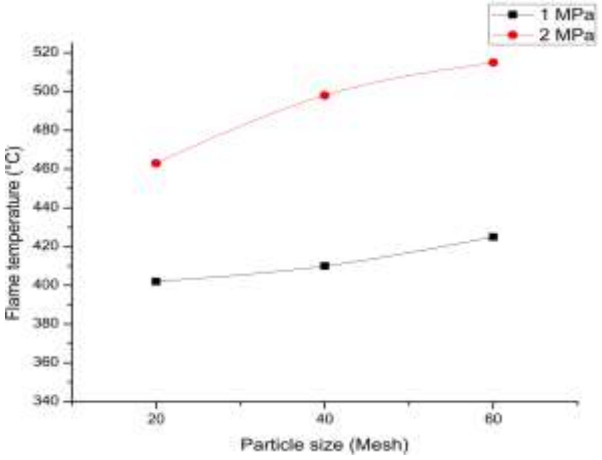


Fig. 7. Flame Temperature Characteristics

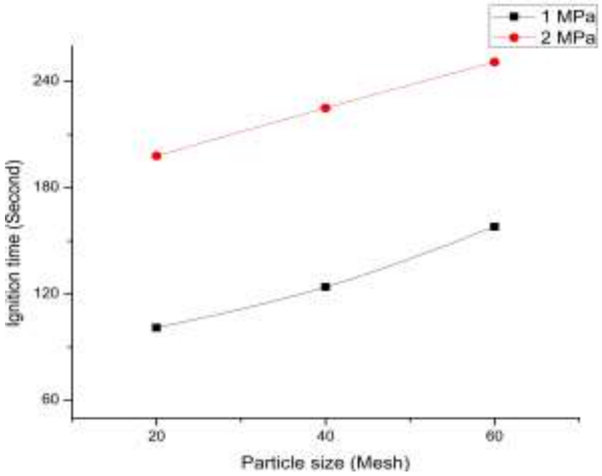


Fig. 8. Ignition Time Characteristics

Figure 9 displayed the effect of particle size and compacting pressure on burning time of *Pterocarpus indicus* twigs waste briquette. Similar to the previous two characteristics, the value of burning time increases with finer particle size and higher compacting pressure. The longest burning time (6590 seconds) is obtained from *Pterocarpus indicus* twigs waste briquette with 60 mesh particle size and compacting pressure of 2 MPa. Studies conducted by Bahttarai et al and Willyanto et al supported the effect of reduced particle size and increased pressure in rising the burning time of briquette [2, 43].

Figure 10 shows the influence of particle size and compacting pressure for the combustion rate of *Pterocarpus indicus* twigs waste briquette. In contrast with the three previous characteristics, the combustion rate value dropped as the particle size of biomass becomes smaller and the pressure used for compacting the briquette increases. The highest combustion rate (0.00366 gram/second) is obtained from *Pterocarpus indicus* twigs waste briquette formed from biomass with 20 mesh particle size and compacting pressure of 1 MPa. The reduction of combustion rate as result of higher pressure and smaller particle size is in accordance with previous studies conducted by Thabuot et al, Davies et al and Chin et al [35,42,45].

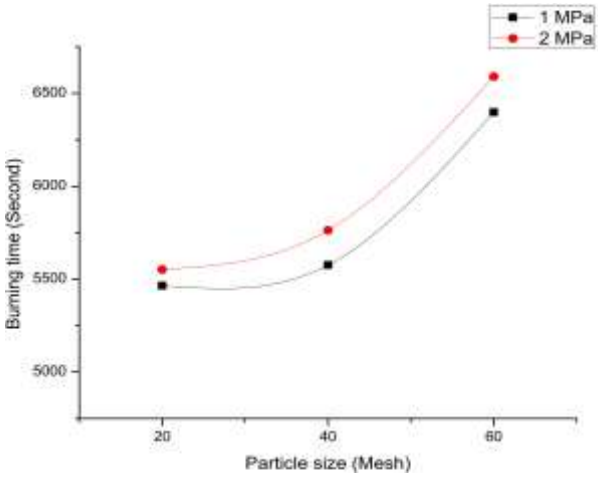


Fig. 9. Burning Time Characteristics

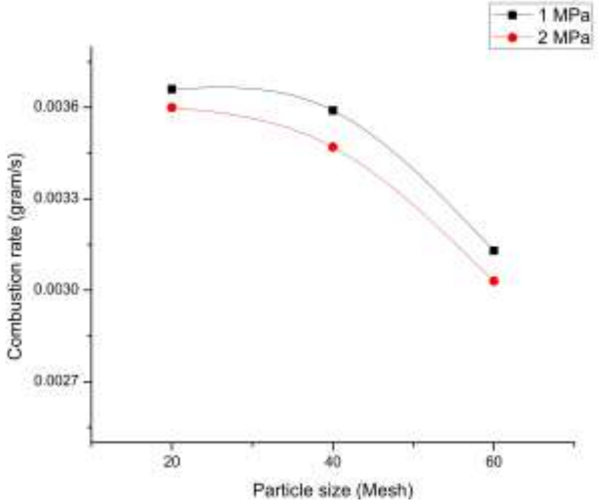


Fig. 10. Combustion rate Characteristics

Some studies have investigated the calorific value of briquette from various biomass. Lela *et al* have investigated the calorific value of sugarcane briquette (3903 Kcal/Kg) and rice straw briquette (3927 kcal/kg) [49]. The highest calorific value obtained from this study (90% twigs waste – 10% tapioca blend) is used as a basis to compare the calorific value of various biomass briquettes. Compared with the briquette caloric value obtained from this study, it is apparent that briquette derived from *Pterocarpus indicus* twigs waste is comparable with the biomass briquette made of any other material. The calorific value difference between *Pterocarpus indicus* twigs waste briquette and other briquettes is small. Furthermore, the advantages of using *Pterocarpus indicus* twigs waste to clean the street of Surabaya city, avoiding unnecessary burning and wasting energy, and preventing the competition of fuel derived from the edible sources are far more superior than the small calorific value difference with other biomass briquettes.

4. Conclusion

Pterocarpus indicus twigs waste is a viable raw material for biomass briquette. The positive effects it brings to Surabaya city and its properties as a renewable energy source will be an asset in tackling the energy issue. Both proximate and ultimate analysis results support the viability of *Pterocarpus indicus* twigs waste as briquette. The highest calorific value was obtained with the proportion of 90% *Pterocarpus indicus* twigs waste and 10% tapioca mixture. The correlation of particle size to briquette quality has been investigated and the result indicates a positive increase in briquette quality with smaller particle size. As for the effect of compacting pressure, the higher magnitude of pressure leads to higher quality of briquette. The best parameters used for creating *Pterocarpus indicus* twigs waste briquette are obtained by utilizing particle size of 60 mesh and pressure of 2 MPa. *Pterocarpus indicus* twigs waste briquette with these level of particle size and pressure has a flame temperature of 515 °C, ignition time of 251 seconds, burning time of 6590 seconds, and combustion rate of 0.00303 gram/second.

Acknowledgments

Thanks to Petra Christian University Indonesia and Direktorat Jendral Pendidikan Tinggi Kementerian Riset Teknologi dan Pendidikan Tinggi Republik Indonesia (Hibah Penelitian Produk Terapan 2016-2017) for their supports during this research.

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