PAPER • OPEN ACCESS
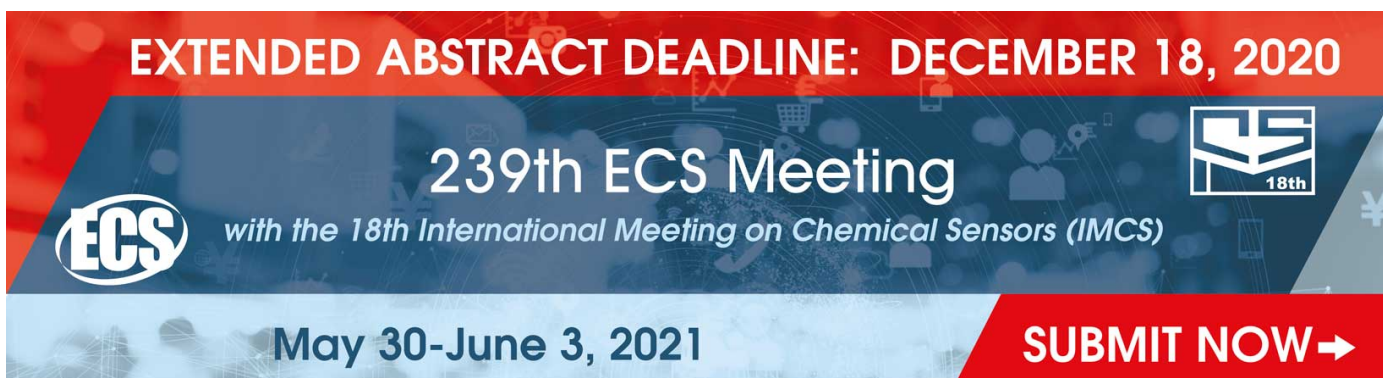
Combustion Performance of *Pterocarpus indicus* Leaves Wastes Briquette with Rejected Papaya as Binding Agent

View the article online for updates and enhancements.

Combustion Performance of *Pterocarpus indicus* Leaves Wastes Briquette with Rejected Papaya as Binding Agent

Willyanto Anggono[1,2], Sutrisno[1,2], Fandi D. Suprianto[1,2], F.X. Yulio Arifin[1,2], and Gabriel Jeremy Gotama[3,4]

1 Mechanical Engineering Department, Petra Christian University, Surabaya, Indonesia
2 Centre for Sustainable Energy Studies, Petra Christian University, Surabaya, Indonesia
3 School of Mechanical and Aerospace Engineering, Nanyang Technological University, Singapore
4 Department of Mechanical Engineering, Technical University of Munich, Garching, Munich, Germany
E-mail: kj-mesin@petra.ac.id

Abstract. *Pterocarpus indicus* is a plant commonly found in Indonesia and it produces wastes from its leaves falling. Earlier investigation indicated that transforming these leaves into briquette could clean them and provide a new source of energy. However, the use of tapioca as binding agent in the previous study may be criticized for affecting the food availability as it is edible. To solve this issue, tapioca is substituted with rejected papaya. The briquette was then investigated to find out the best manufacturing parameters and its viability as a sustainable fuel. The optimum ratio of *Ptercarpus indicus* leaves waste and rejected papaya, which yield calorific value of 4338.79 Kcal/kg, is found to be 95% and 5%, respectively. Proximate and ultimate analyses corroborate the use of this briquette. Investigation of four combustion parameters (ignition time, flame temperature, combustion rate, and burning time) indicates that the best briquette is manufactured with biomass of 60 mesh size or 250 μm and compacted with hydraulic pressure of 2 MPa.

1. Introduction

The increase of the overall human population reduces the supply of available fossil fuel [1,2]. This situation promotes the development of modern sustainable fuels. The cost of fuel may stabilize with the addition of new sources of renewable energy [3,4]. Biomass has been investigated meticulously for its potential as a sustainable fuel. Various types of biomass comprise of factory waste, algae, wood, city and animal wastes. The convenience of acquiring the biomass with low price to no cost is one of its advantages [5]. Biomass also has the potential to be a CO_2 neutral fuel [5].

General process of using energy residing in the biomass is by directly combusting it [6]. However, direct combustion requires certain condition. High water content in biomass will stop the combustion to take place and biomass with high water content are prevalent [4]. Therefore, it is crucial for the biomass to be processed as to decrease its water content. Another weakness of the direct combustion is in logistic. Biomass requires large space due to its low bulk density which translates to higher expenditure when transporting it [7].

The disadvantages of directly combusting the biomass can be solved by turning them into briquette, which has better energy and bulk density, better heating value, better energy properties, and less water

content [7-9]. Furthermore, the energy obtained from the use of briquette is larger compared to the energy needed to convert the biomass into briquette [10]. In social context, briquette is beneficial to society by decreasing the scarcity of energy and providing additional income, particularly to those who lives in rural area [5,11].

Plant waste has been recognized as a potential biomass fuel [12]. Indonesia, a developing country with tropical climate, has an abundant source of plant biomass [5], including *Pterocarpus indicus* leaves wastes. *Pterocarpus indicus* trees are generally found in the street of Indonesia and create a surfeit amount of litters in the form of leaves. An example of the *Pterocarpus indicus* plant commonly seen in Indonesia is displayed in Figure 1. It may be observed from this figure that the leaves that fall from the tree become litters. To clean these litters, people commonly burn these leaves. The burning of leaves generates additional greenhouse emission and wasting possible energy source. Turning these litters of leaves into briquette is a viable solution to stop the mistreatment of *Pterocarpus indicus* leaves wastes. The preceding investigation has discovered the possibility of manufacutring briquette using *Pterocarpus indicus* leaves wastes and tapioca flour as its binder [4]. However, the use of tapioca as binding agent in that study may be criticized for it is an edible source and therefore affects the food availability. To solve this issue, rejected papayas are used as the binding agent instead. Rejected papayas, as shown in figure 2, are papayas that are not sold or consumed due to their lack in quality during sorting process. Their sugar and natural fibre content make it possible to use them as binder for briquette. Most of the time, they are left to rot, causing odour problem and unsightly view. Hence, rejected papayas are considered to be wastes and their utilization is useful in reducing them.

Figure 1. *Pterocarpus indicus* tree found in Indonesia. Leaves wastes are seen beneath it.

Figure 2. Rejected papayas that are left to rot and become unpleasant to look.

In this study, the investigation focuses mainly in obtaining the best briquette that is made of *Pterocarpus indicus* and rejected papaya. Crucial attributes that affect the quality of the produced briquette are compacting pressure, ratio of biomass to binder, and particle size of the biomass [2,13]. This study was conducted to discover the optimum level of these parameters. Firstly, the optimum proportion of biomass and binder is found by comparing their calorific value. Afterward, the best proportion of briquette underwent proximate and ultimate analyses. Optimum particle size and compacting pressure were found through testing of ignition time, combustion rate, flame temperature, and burning time.

2. Experimental method

Firstly, in order to manufacture the *Pterocarpus indicus* leaves wastes and rejected papaya briquette, the raw materials are gathered. Both leaves and rejected papaya were easy to obtain and only require little to no cost. After obtaining both materials, the moisture content in the leaves were reduced by directly exposing them to sunlight for 3 days. As for the rejected papayas, the papayas were squashed into liquid to prepare them as binder, as shown in figure 3. Subsequently, the dried leaves were cut into several smaller pieces according to the pre-determined particle size required for the investigation.

Afterward, the shredded leaves were combined with the squashed papayas in a mould. The mould was then exposed to a hydraulic pressure to compact both leaves and papaya into briquette. The final result of the briquette is displayed in figure 4. The acquired briquettes, which were manufactured distinctively under numerous combinations of proportion, size, and pressure, were then tested to find out their best proportion, proximate and ultimate analyses, and combustion characteristics.

Figure 3. Squashed rejected papaya.

Figure 4. Result of *Pterocarpus indicus* leaves waste and rejected papaya briquette.

In this investigation, the proportion of biomass to rejected papaya is varied from 75% biomass-25% rejected papaya to 95% biomass-5% rejected papaya with a 5% increment of biomass proportion. The estimation of the calorific value was performed using 1341 Plain Coat oxygen bomb calorimeter to determine the calorific value of briquette for each proportion.

Proximate and ultimate analyses were also performed on the manufactured briquettes. The result of the proximate analysis provides insight to the fuel's properties including volatile matter and water content which are crucial when discussing the fuel's viability in society. The result of ultimate analysis provides insight to the essential elemental composition of the briquette including carbon, hydrogen, nitrogen, and oxygen. All of these tests were performed under ASTM standards.

In investigating the effect of biomass size, 3 distinct particle sizes were chosen, 60 mesh or 250 μm, 40 mesh or 420 μm, and lastly, 20 mesh or 840 μm. In investigating the effect of applied hydraulic pressure, two degree of pressure were exposed to the briquette, 1 MPa and 2 MPa. The mould is 50 mm in length and 12.5 mm in radius. Several briquettes were manufactured through numerous combinations of three distinct sizes and two distinct pressures. The results were then tested to find the best combination of particle size and pressure which yield the best briquette. Combustion characteristics such as ignition time, flame temperature, combustion rate, and burning time of the briquette were examined to ascertain the briquette's performance as renewable fuel. The combustion characteristics test was conducted for 3 repetitions for each combination of particle size and pressure to ensure the significance of the results.

3. Results and discussion

The calorific value for various ratio of *Pterocarpus indicus* leaves waste and rejected papaya blend is shown in figure 5. The results suggested that briquette made of 95% *Pterocarpus indicus* leaves waste and 5% rejected papaya has the highest calorific value. This result is due to the *Pterocarpus indicus* leaves waste having higher calorific value (4427.62 Kcal/kg) [4] compared to rejected papaya (435.02 Kcal/kg) and therefore larger proportion of *Pterocarpus indicus* leaves wastes increases the overall calorific value of the briquette. According to figure 6, the calorific value obtained in this study is comparable to the *Pterocarpus indicus* leaves wastes briquette with tapioca as binder and others biomass briquettes [13-15]. Briquette bonded with tapioca has higher calorific value since tapioca has larger calorific value (3574.47 Kcal/kg) [4] as opposed to rejected papaya (435.02 Kcal/kg).

The results of the ultimate and proximate analyses are given in table 2 and 3, respectively. The low moisture content, and the lower fixed carbon value compared to the volatile matter indicates that the briquette can be easily combusted [16]. The sulfur content is considered to be within acceptable range as compared to other briquettes such as *Cerbera manghas* leaves (0.19%) [13], rice straw/sugarcane leaves (± 0.04%) [14], *Pterocarpus indicus* twigs (0.17%) [16], areca leaves (± 0.6%) [17], and water

hyacinth charcoal (± 0.36%) [18]. The ultimate analysis results indicate the combination of both hydrogen and carbon in briquette is higher than 50 %wt in which they contribute to the calorific value of the briquette [16]. These analyses corroborate the use *Pterocarpus indicus* leaves waste and rejected papaya briquette as fuel.
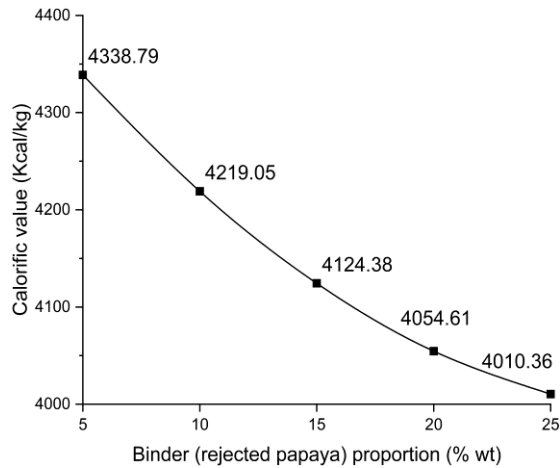
Figure 5. Calorific value of *Pterocarpus indicus* leaves waste and rejected papaya for various proportion (5% to 25%wt of rejected papaya).
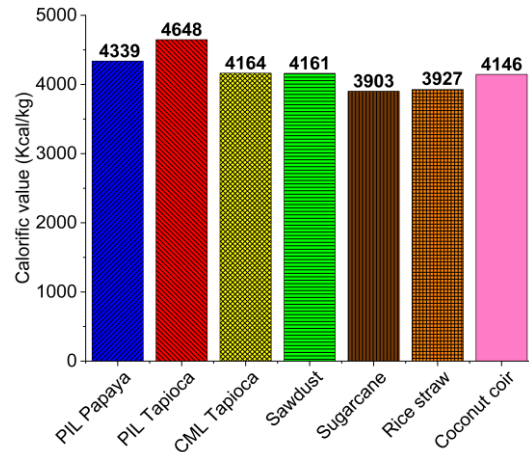
Figure 6. Comparison of various briquettes calorific value [13-15]. PIL is an abbreviation for *Pterocarpus indicus* leaves. CML is an abbreviation for *Cerbera manghas* leaves.

Table 2. Proximate analysis results.

Parameters	Unit	As Received	Dried Basis	Test Method
Total Moisture	%wt	11.15	-	ASTM D 3302 – 17
Ash Content	%wt	6.82	7.68	ASTM D 3174 – 12
Volatile Matter	%wt	66.30	74.62	ASTM D 3175 – 18
Fixed Carbon	%wt	15.73	17.70	ASTM D 3172 – 13
Total Sulfur	%wt	0.22	0.25	ASTM D 4239 – 18
Gross Calorific Value	Kcal/ Kg	4341	4886	ASTM D 5865 - 13

Table 3. Ultimate analysis results.

Parameters	Unit	As received	Test Method
Carbon	%wt	46.12	ASTM D 5373–16
Hydrogen	%wt	5.09	ASTM D 5373–16
Nitrogen	%wt	3.58	ASTM D 5373–16
Oxygen	%wt	27.02	ASTM D 3176–15

The influence of various particle sizes and hydraulic pressures on the flame temperature is given in figure 7(a). High flame temperature is desired as it contributes to higher rate of heat transfer. Smaller particle size and larger pressure resulted in larger flame temperature. Peak flame temperature (586 °C) is found in briquette with 2 MPa compacting pressure and biomass size of 60 mesh.

The influence of various particle sizes and hydraulic pressures on the ignition time is given in figure 7(b). Ignition time relates to the time required for the briquette to be ignited [19]. Longer ignition time means that the briquette requires more time to be combusted. Smaller particle size and larger pressure

resulted in larger ignition time for the briquette. Peak ignition time (295 seconds) is found in briquette with 2 MPa compacting pressure and biomass size of 60 mesh.

The influence of various particle sizes and hydraulic pressures on the burning time is given in figure 7(c). Burning time shows the time required for the fuel to reduce into ashes after being ignited [19]. Longer burning times means that the briquette last longer when used as fuel. Smaller particle size and larger pressure resulted in slightly larger burning time of the briquette. Peak burning time (4394 seconds) is found in briquette with 2 MPa compacting pressure and biomass size of 60 mesh.

The influence of various particle sizes and hydraulic pressures on the combustion rate is given in figure 7(d). Combustion rate shows the rate of which the combustible component of the fuel is consumed when combusted. Larger burning rate means that the briquette burns at a faster rate and therefore will not last for long. Smaller particle size and larger pressure resulted in slightly less combustion rate of the briquette. The smallest combustion rate (0.00253 gram/second) is found in briquette with 2 MPa compacting pressure and biomass size of 60 mesh.

The result of the burning time and combustion rate only have a slight difference between different hydraulic pressures. However, these results are in line with the previous studies where larger hydraulic pressure leads to longer burning rate and larger combustion rate [2,16].
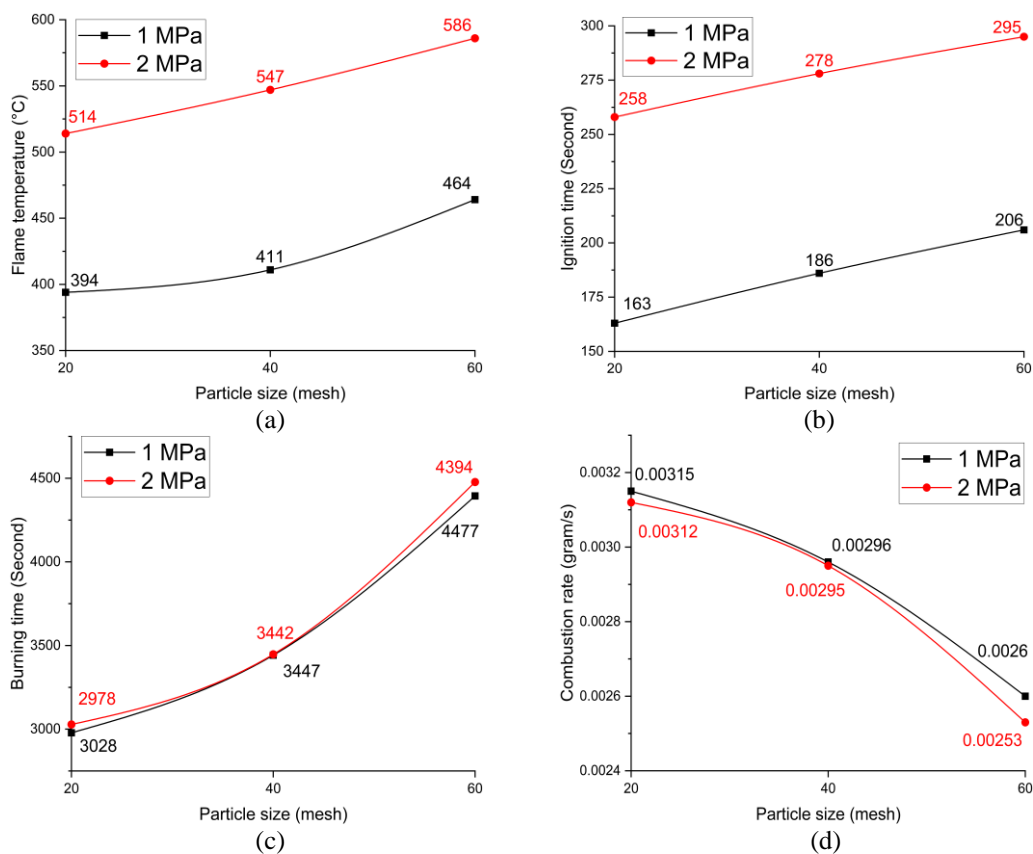
Figure 7. (a) flame temperature, (b) ignition time, (c) burning time, and (d) combustion rate of briquette at various particle size and compacting pressure.

4. Summary

The result of this study suggests that briquette manufactured with ratio of *Pterocarpus indicus* leaves wastes and rejected papaya of 95% and 5%, respectively, yields the highest calorific value of 4338.79 Kcal/kg. The calorific value of the briquette bonded with rejected papaya is comparable with other types of briquette and slightly lower compared to briquette bonded with tapioca due to their respective binder's calorific value. Ultimate and proximate analyses support the use of *Pterocarpus indicus* leaves waste and rejected papaya briquette. Burning time, ignition time, and flame temperature raises

with the increase of the applied hydraulic pressure and reduction of the shredded biomass size. In the other hand, the reduction of applied hydraulic pressure and the raise of biomass size increase the combustion rate. 60 mesh (250 μm) particle size and 2 MPa hydraulic pressure were found to be the best manufacturing parameters for the briquette. Briquette manufactured under these attributes has 4394 seconds of burning time, 295 seconds of ignition time, 586 °C of flame temperature, and 0.00253 gram/second of combustion rate.

While 60 mesh particle size and 2 MPa hydraulic pressure are the most optimum manufacturing attributes discovered in this investigation. Universally, it might not be the best parameters for manufacturing *Pterocarpus indicus* leaves waste and rejected papaya briquette. Prospective studies may investigate the biomass size and hydraulic pressure comprehensively through addition of larger hydraulic pressure and much finer particle size. Another alternative binding agent may also be investigated in the future; Particularly, those that increase the overall calorific value of the briquette without affecting the availability of the food source.

5. References

[1]   Jones G A and Warner K J 2016 *Ene. Pol.* **93** 206–12
[2]   Anggono W, Suprianto F D, Gotama G J, Sutrisno and Evander J 2018 *IOP Conf. Ser.: Mater. Sci. Eng.* **417** 012007
[3]   Sarkar A and Praveen G 2016 *Biofuels and Bioenergy Int. Conf.* (India) (Switzerland: Springer International Publishing AG) p 117
[4]   Anggono W, Sutrisno, Suprianto F D and Evander J 2017 *IOP Conf. Ser.: Mater. Sci. Eng.* **241** 012043
[5]   Sugumaran P and Seshadri S 2010 *Biomass Charcoal Briquetting Technology for Alternative Energy Based Income Generation in Rural Areas* (India: Shri AMM Murugappa Chettiar Research Centre)
[6]   Thipkhunthod P, Meeyoo V, Rangsunvigit P, Kitiyanan B, Siemanond K and Rirksomboon T 2005 *Fuel* **84** 849–57
[7]   Sengar S H, Mohod A G, Khandetod Y P, Patil S S and Chendake A D 2012 *Int. J. Ene. Eng.* **2** 28–34
[8]   Mwampamba T H, Owen M and Pigaht M 2013 *Ene. Sust. Dev.* **17** 158–70
[9]   Stolarski M J, Szczukowski S, Tworkowski J, Krzyżaniak M, Gulczyński P and Mleczek M 2013 *Renew. Ene.* **57** 20–6
[10]   Sakkampang C and Wongwuttanasatian T 2014 *Fuel* **115** 186–9
[11]   Hu J, Lei T, Wang Z, Yan X, Shi X, Li Z, He X and Zhang Q 2014 *Energy* **64** 557–66
[12]   Anggono W, Noor MM, Suprianto F D, Lesmana L A, Gotama G J and Setiyawan A 2018 *Int. J. of Auto. And Mech. Eng. (IJAME)* **15** 5667-82
[13]   Anggono W, Suprianto F D, Sutrisno and Kasrun A W 2016 *Int. J. Ind. Res. and App. Eng.* **1** 11–4
[14]   Jittabut P 2015 *Ene. Proc.* **79** 2-9
[15]   Lela B, Barišić M and Nižetić S 2016 *Waste Man.* **47** 236-345
[16]   Anggono W, Sutrisno, Suprianto F D, Evander J and Gotama GJ 2018 *Int. J. Ren. Ene. Res.* **8** 1393-400
[17]   Deepak K B, Manujesh B J, Vivek, Yashas B K 2019 *AIP Conf. Proc.* **2080** 030004
[18]   Suttibak S, Loengbudnark W 2018 *IOP Conf. Series: Mater. Sci. Eng.* **297** 012001
[19]   Kabok P A, Nyaanga D M, Mbugua J M and Eppinga R 2018 *J. Petrol. Env. Biotech.* **9** 100370