IOP Conference Series:
Earth and
Environmental Science

PAPER • OPEN ACCESS

Carbonization effect on EFB briquettes prepared with different type of binders

To cite this article: M M Nazari *et al* 2020 *IOP Conf. Ser.: Earth Environ. Sci.* **476** 012072

IOP Conf. Series: Earth and Environmental Science **476** (2020) 012072 doi:10.1088/1755-1315/476/1/012072

Carbonization effect on EFB briquettes prepared with different type of binders

M M Nazari[1,2], M Y Idroas[1] and F A Ayuni[2]

[1]School of Mechanical Engineering, Universiti Sains Malaysia, 14300 Nibong Tebal, Pulau Pinang, Malaysia
[2]School of Bioprocess Engineering, Universiti Malaysia Perlis, 02600 Arau, Perlis, Malaysia

E-mail: muniranazari@unimap.edu.my

Abstract. Biomass energy is gaining public interest as a result of the environmental impacts and depletion of fossil fuel resources. Thus, biomass briquettes have emerged as an attractive option due to its huge renewable energy potential. The biomass briquettes are used for thermal applications because it can produce complete combustion as it has consistent quality and high burning efficiency. However, the quality of the briquettes can be added by application of carbonization treatment method. Carbonization of biomass is a waste treatment process in which a biomass is heated in an oxygen-free or oxygen-limited environment. In this study, carbonized EFB was blended with binders and densified into briquettes. The mixing ratio of binders to carbonize EFB were fixed at 20%. The effect of the carbonization treatment on the briquette properties and combustion characteristics was studied through proximate and ultimate analysis while high heating value (HHV) was analyses by using bomb calorimeter. To explore the potential of carbonized EFB briquettes, the results were compared to untreated EFB briquettes. Results indicate briquette TS2 as the optimum formulation since it owned moderate physicochemical properties. In addition, the briquette had highest HHV of 23.62 MJ/kg which is approximately 30% higher than briquette prepared from untreated EFB. Overall, carbonized EFB blended with tapioca starch was found to improve the briquette quality and enhance the possibility to use as syngas production.

1. Introduction

In 11th Malaysia Plan (2016-2020), one of the government encouragement is to reduce the nation's dependency on fossil fuels for electricity generation by increasing the use of renewable energy such as biomass, biogas, solar and wind as replacement to fossil fuel [1]. Biomass briquette is one of an alternative as they are renewable, non-polluting and an economic of energy sources. Briquette have wide applications as fuel either for household usage or industrial application especially in producing heat and electricity generation [2]. Briquette is produce by compacting the biomass residue into a uniform solid fuel and the sources of biomass briquette are mostly from agricultural and forestry residue.

At the same time, Malaysia also well known as second largest producer and exporter of palm oil globally. The report from Malaysian Palm Oil Board (MPOB) in 2017 stated about 23% of Malaysia total land area (5.74 million hectares) is planted by oil palm [3]. However, high volume of palm oil waste also produced especially from milling activity and it's reported 22% of palm oil mill residual are empty fruit bunch (EFB) [4]. Even though, EFB offers great potential as a cost-effective feedstock for producing briquettes, as fibrous structure material, producing briquettes from EFB facing several challenges such as poor grind ability, high moisture content and low energy density [5]. Poor grind ability causes high energy consumption and create challenges during briquette preparation. While, as for high moisture content, it lowers the maximum combustion temperature and increase pollutant emissions. Therefore, there is a need for biomass pretreatment to improve chemical and physical properties by increasing the energy content and grind ability [6]. To overcome this issues, carbonization treatment is apply to improve the raw material properties. Carbonization treatment is a thermochemical conversion method where biomass waste is subjected to thermal heating in the absence of air and will produce about 33% of char.

The quality of the briquette also depends on the strength of the briquette for storage and transportation purposes. It is difficult to obtain strong briquettes without adding any binding agent or solution. At the same time, types of binder, amount of binder agent and water addition have significant effects on the thermal behaviour and combustion of the briquettes [7]. Therefore, for this purpose, various binding agents either non-combustible or directly harmful to the environment have been used [8]. Starch, molasses, organic waste, limestone, dolomite, bitumen, etc are the well-known binding agents used by the industry [9]. In this study, binding solution such as tapioca starch and corn starch are chosen to blend with the carbonized EFB for briquetting process due to its low cost and organic content. Organic content tend to burn away, leaving very little or no residue behind which is good for decomposition.

The main objective of this study was to examine the influence of carbonization treatment and starch binder solution towards the combustion characteristics of briquettes produced from carbonized EFB. Besides that, combustion analysis was carried out to predict the possibility of briquette to generate producer gas in second combustion process which is through gasification process.

2. Materials and methods

2.1. Materials

The empty fruit bunch (EFB) fiber was collected from Taclico Company Sdn Bhd in Kulim, Kedah, Malaysia and dried under the sun for 3 – 4 days. After that, samples were chipped into a small pieces and separated into two groups which are group A and group B. Group A was for untreated briquette while group B undergo carbonization treatment process.

2.2. Apparatus and experimental procedure

For group B, the EFB samples were carbonized using a rotary carbonizer as shown in Figure 1. The rotary carbonizer are equipped with a thermocouple and temperature controller where it can reach the maximum temperature of 400℃. In this process, 1 kg of sample was loaded into the machine and with controlled speed of 30 rpm, the rotary carbonizer was heated to the target temperature of 350℃. Once the temperature was reached, the sample was held for further 45 minutes before the machine was cooled to the ambient temperature. Figure 2 shows the result of carbonized EFB after the treatment. From this process, the carbonized EFB produced are approximate 300 g.

Figure 1. Rotary carbonizer

Figure 2. Carbonized EFB

Then, carbonized EFB were ground and sieves into small particle size of 1 mm and blended with the binder solution. In this study, two different type of binders were used which are tapioca starch (TS) and corn starch (CS) with ratio water to starch 100:20, 110:20 and 120:20 for each 100g of carbonized EFB. Binder solution was added into the carbonized EFB proportionally and the mixtures were thoroughly stirred. Briquette is produced through densification process. In this process, all mixture samples were compacted by using cylindrical mould of 3 cm x 3cm. After that, the briquettes were dried under the sun for 3 – 4 days. Lastly, the briquettes as shown in Figure 3 were kept in a closed tight container to minimize moisture absorption from the surrounding humidity. For group A samples, raw EFB were ground to 1 mm particle size and densified without binder.

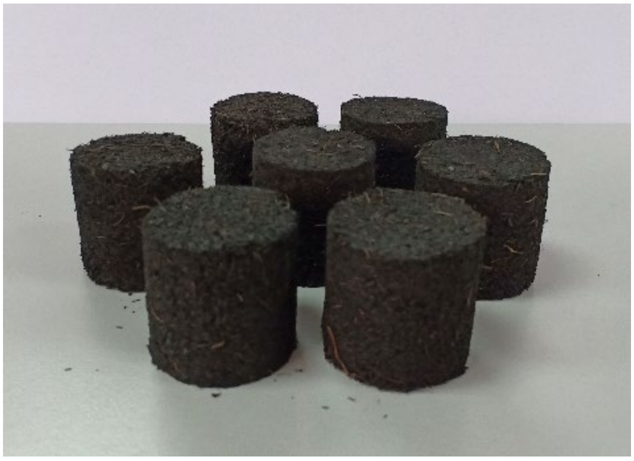

Figure 3. Carbonized EFB Briquette

2.3. Analysis

Physical, proximate, ultimate and high heating value (HHV) analysis were conducted to determine the physicochemical and combustion properties for each of the briquettes. The physical analysis was measured using universal material testing machine to determine the maximum compressive load of the briquettes. Proximate analysis was carried out by using Perkin Elmer Pyris 1 Thermogravimetric Analyzer (TGA) with according to ASTM standard technique to analyse the amount of volatile matter (VM), fixed carbon (FC), moisture content (MC) and ash content of the briquettes. In this test, approximately 10 mg of the briquettes was placed in the aluminium sampling cup and heated from 50°C to 800°C at 10°C/min heating rate and nitrogen (N_2) (flow rate of 25 ml/min) as sweeping gas.

While, the ultimate analysis which is to determine the composition of carbon, hydrogen, nitrogen, and sulphur contents were conducted via an Elemental Analyzer Agilent module 4890. Then, the oxygen content was calculated by difference. Lastly, the HHV was measured using Nenken 1013-B bomb calorimeter.

3. Results and discussions

Through analysis, fuel characteristics of the briquette are determined to study the effect of the carbonization treatment and binder on the briquette produced.

3.1. Physicochemical properties

3.1.1. Physical analysis. Physical analysis is study to determine the effect of binder on the physical property of the briquette as a reference to identify the best quality carbonized briquette produced. The evaluation of physical property was measured through the maximum compressive load can be retained by the carbonized briquette. From the testing, maximum compressive load achieved by raw EFB briquette is 230 N while results for carbonized EFB briquette blended with various starch mixtures are shown in Table 1.

Table 1. Effect of binder solution on the maximum compressive load of the carbonized EFB briquette.

Briquette Treatment (carbonized EFB:starch solution)		Label	Maximum Compressive Load (N)
Tapioca starch	100:100/20	TS1	320
	100:110/20	TS2	431
	100:120/20	TS3	550
Corn starch	100:100/20	CS1	243
	100:110/20	CS2	410
	100:120/20	CS3	505

Based on the results obtained, briquettes with carbonization treatment blended with starch mixture increase the strength of the briquette compare to raw EFB briquette. This is due to briquette is bonding better with the addition of starch and maintaining their compacting form after densification process. It was also observed that the effect of the binder differed for the type and solution of the binders. As shown in Table 1, briquette strength increase with increasing of the starch solution viscosity for both type of binders. This is indicating that strong briquette formed better after the appropriate amount of binder was introduced. The results also showed tapioca starch gave more strength effect compared to corn starch as percentage of lignin content from tapioca in the tapioca starch higher than corn starch.

3.1.2. Proximate analysis. Results of proximate analysis are presented in Table 2. Based on the results, it showed carbonization treatment obviously changes the proximate properties of briquette and the tapioca starch enhance the quality of the carbonized briquette. In this study, carbonized briquette made with tapioca starch solution ratio 100:20 (TS1) had the highest fixed carbon content, lower volatile matter and lower ash content of 56.938, 26.42 and 5.715 respectively. As reported by Du et al [10], high fixed carbon content is favoured as this will give substantial contribution to thermal energy release when it is burned, particularly for second gasification process generation. Besides that, even though briquette with low volatile content might difficult to ignite but it will produce less smoke during burning process [11].

Table 2. Effect of carbonization and binder on the fixed carbon, volatile matter, ash content and moisture content of the briquette.

Component (%)	Treatment						
	Raw	TS1	TS2	TS3	CS1	CS2	CS3
Fixed carbon	13.05	56.938	54.438	52.113	50.998	50.887	50.023
Volatile matter	80.21	26.42	29.741	32.126	31.721	35.918	35.209
Ash content	6.43	10.927	8.742	7.498	10.6	5.478	7.283
Moisture content	15.8	5.715	7.143	8.263	6.619	7.719	7.458

The effects of the binder content differed for the types and solution of binder. Even though the difference is smaller but from this study its showed tapioca starch as a binder produced lower volatile matter content compare to corn starch. The difference on volatile matter reduction between this two starch types was due to variance in cellulosic content mainly carbohydrate content which are easily degraded during thermal treatment and also due to the percentage of moisture content [12].

The results in Table 2 also showed fixed carbon content decrease and volatile matter increase significantly with water ratio to starch increase. Amount of water for the starch solution definitely effect the moisture content of carbonized EFB briquettes which slower down the decomposition of volatile matter in the briquettes. Lastly, the high ash value of carbonized EFB compared to raw briquette is noteworthy because ash is known to negatively affect the HHV [13].

3.1.3. Ultimate analysis and high heating value. The results of the ultimate analysis and HHV of raw briquette and carbonized briquette blended with different type of binders are listed in Table 3. From the Table, results gained indicate that carbonized EFB increase the carbon content and decrease the oxygen content which indicating increased energy densities of the briquette. Elemental carbon (C) increased approximately to 14.7%, while elemental oxygen (O) reduction were up to 8.8%.

In view of type of starch effect on the briquette properties, tapioca starch with water to starch ratio 110:20 give better properties. As referred to Table 3, carbonized briquette TS2 released the highest carbon content and lowest oxygen content compared to carbonized briquette prepared from others starch mixture. Higher oxygen element tends to decrease the HHV of the briquette. However, overall results of the ultimate analysis indicates that carbonized EFB briquette develop in this study is environmental friendly with only trace amounts of nitrogen (N) and sulfur (S). A trace amount nitrogen and sulfur contents indicating the thermal conversion of the fuel will result in low concentrations of nitrogen oxides (NOx) and sulfur oxides (SOx) [14].

Table 3. Effect of carbonization treatment and binder on carbon, hydrogen, nitrogen, oxygen and sulphur of briquette.

Properties		Treatment						
		Raw	TS1	TS2	TS3	CS1	CS2	CS3
Ultimate analysis (%)	C	54.1	60.270	62.031	59.337	59.097	59.042	58.669
	H	5.85	4.0335	3.9531	3.7169	3.9893	3.9385	4.2611
	N	0.58	0.6353	0.6720	0.6002	0.5847	0.8757	0.8846
	O (diff)	36.5	34.9869	33.2810	36.2868	36.2576	36.052	36.1025
	S	0.09	0.0728	0.0629	0.0591	0.0714	0.0918	0.0828
High Heating Value (MJ/kg)		17.66	22.29	23.62	23.46	19.31	20.66	19.27

HHV is correlated with the ultimate composition of the solid. In this study, HHV of briquettes depends on the main contributors to the heat energy value of biomass material which are carbon and oxygen content. The highest value of 23.62 MJ/kg was obtained by TS2 briquette which is 30% higher than HHV obtained by briquette without treatment. It is also means tapioca starch enhance the quality of the carbonized EFB briquettes compared to corn starch. The results were also compared to others published HHV of briquettes done by other researchers such as rice husk briquette (13.4 MJ/kg) [15], cowpea briquette (14.4 MJ/kg) [16], rice husk and banana residue briquette (16.4 MJ/kg) [17], empty fruit bunch briquette (17.66 MJ/kg) [18] and coconut briquette (29.3 MJ/kg) [19]. From the HHV results, all briquettes fulfill the minimum energy release required for making commercial briquette as state by DIN 51731 which is more than 17.5 MJ/kg.

3.2. Combustion analysis

To evaluate the effects of the type of binder on the combustion behaviour, the briquettes were subjected to thermogravimetric analysis. Through the analysis, the derivative thermogravimetric (DTG) profiles of raw and carbonized EFB briquette blended with different type of binders are compared in Figure 4. In this study, only TS2 and CS2 were used for comparison with the raw briquette as both represent the highest HHV for each binder. Overall, from the results, the combustion behaviour of the carbonized EFB briquette blended with starch showed improvement compared to raw EFB briquette. TS2 and CS2 curves shift to the right showed the degradation process of TS2 and CS2 was faster than raw EFB. This is due to the effect of moisture removal and volatile released during carbonization treatment process.

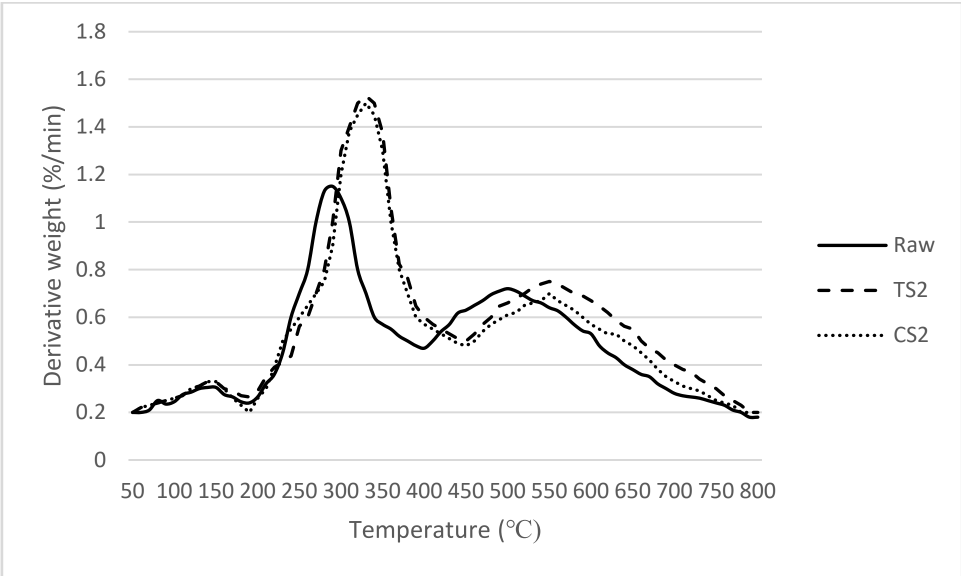

Figure 4. DTG curves of the raw and carbonized EFB briquette blended with different type of binders.

The curves shown in Figure 4 also illustrate the temperature range are divided into three distinguished zones and these trends were found had similar findings by others researchers [20,21]. First zone which is temperature range below 200°C indicates the drying stage. From the curves, a small DTG hump occurred at around 150°C indicating moisture removal for all samples. Meanwhile, the second zone (200-400°C) indicates the decomposition stage of hemicellulose and cellulose. Chemical bond in EFB began to break and the lightest volatile compounds were released. TS2 and CS2 showed better weight loss compared to raw EFB as carbonization treatment had reduce the volatile matter content for the briquettes. However, the high content of volatile matter in raw EFB briquette makes it easy to burn compared to carbonized EFB briquettes. Lastly, the third zone which is temperature range of 400-800°C indicated complete combustion of fixed carbon content for all samples and corresponds to lignin decomposition and char oxidation [22]. For raw EFB briquette, the decomposition of lignin occurred early at 400°C whereas carbonized EFB briquettes at 450°C.

4. Conclusion

The finding of this study shown that physicochemical and combustion properties of the carbonized EFB briquette blended with starch mixture would influence by the type and portion of binder in order to produce good densified solid fuels as a source of energy. The best carbonize EFB briquette found to present by the starch mixture of tapioca starch to water ratio of 100:20 but its having lesser heating value. Therefore, in term of briquetting formulation, the study would concluded that TS2 is the best formulation as it obtained moderate physical property and highest HHV. Overall, the results obtained from this study provide an important reference to generate second generation biofuel product which is producer gas via gasification process. Carbonization had partially devolatized the lignin and hemicellulose content in the briquettes. Thus, it will reduce the generation of tar and increases the quality of gas produced when the carbonized EFB briquettes are gasified.

Acknowledgement

The authors would like to acknowledge School of Mechanical, Universiti Sains Malaysia for providing research facilities and thankful to Ministry of Higher Education, Malaysia under the Research Acculturation Grant Scheme (RAGS) 9018-00087 for the financial support extended to this research.

References

[1] 11th Malaysia Plan (2016-2020) 2016
[2] Oladeji J 2015 *J. Energy Technol. Policy.* **5** pp 72-82
[3] MPOB 2017 *Malaysia oil palm industry performance 2016 and prospects for 2017* (Malaysia: MPOB)
[4] Malaysia-German Chamber of Commerce and Industry 2017 *Oil palm biomass and biogas in Malaysia, 2017* (Malaysia: EUMCCI)
[5] Liu Z and Han G 2015 *Fuel* **158** pp 159-65
[6] Norfadhilah H, Tokimatsu K and Yoshikawa K 2019 *Sustainability* **11** pp 1-23
[7] Altun N, Hicyilmaz C and Bagci A 2003 *Energy & Fuels* **17** pp 1266-76
[8] Yaman S, Sahan M, Haykiri-Acma H, Sesen K and Kucukbayrak S 2001 *Fuel Processing Tech.* **72** pp 1-8
[9] Sahan M 1999 *Usage of biomass in the production of briquettes* (Istanbul: Istanbul Technical University)
[10] Du S W, Chen W H and Lucas J A 2014 *Bioresour. Technol.* **161** pp 333-9
[11] Onuegbu O A, Ekpunobi U E, Ogbu I M, Ekeoma M O and Obumselu F O 2011 *IJRRAS* **7** pp 153-59
[12] Park J, Meng J, Lim K H, Rojas O J and Park S 2013 *J. Anal. Appl. Pyrolysis* **100** pp 199-206
[13] Dermibas A and Arin G 2002 *Energy Sources* **24** pp 471-82
[14] Nyakuma B B, Johari A, Ahmad A and Tuan Abdullah T A 2014 *J Teknologi* **67** pp 79-82
[15] Oladeji J T and Sc M 2010 *Pacific J. Sc. Technol.* **1** pp 101-06
[16] Enweremadu C C, Ojediran J O, Oladeji J T and Afolbi I O 2004 *Sci. Focus* **8** pp 18-23
[17] Nazari M M, Chin P S and Atan N A 2019 *Int. J. Adv. Sci. Eng. Information Technol.* **9** pp 455-60
[18] Nasrin A B, Choo Y M, Joseph L and Micheal S 2011 *J. Eng. App. Sci.* **6** pp 446-51
[19] Yerizam M, Marsi M and Novia N 2013 *Int. J. Adv. Sci. Eng. Information Technol.* **3** pp 232-38
[20] Mohammed M A A, Salmiaton A, Wan Azlina W A K G and Mohamad Amran M S 2012 *Bioresour. Technol.* **110** pp 628-636
[21] Matali S, Rahman N A, Idris S S, Yaacob N and Alias A B 2016 *Procedia Eng.* **148** pp 671-678
[22] Lapuerta M, Hernandez J J, and Rodriguez J 2004 *Biomass & Bioenergy* **27** pp 385-391