Progress in Engineering Application and Technology Vol. 2 No. 1 (2021) 038-049

PEAT

Homepage: http://publisher.uthm.edu.my/periodicals/index.php/peat
e-ISSN : 2773-5303

Production of Smokeless Biofuel Briquettes from Palm Kernel Shell Assisted with Slow Pyrolysis Treatment

Nurul Alia Mohamad Azman[1], Nasrul Fikry Che Pa[1]*

[1]Department of Chemical Engineering Technology, Faculty of Engineering Technology,
Universiti Tun Hussein Onn Malaysia, 84600 Pagoh, Johor, MALAYSIA

*Corresponding Author Designation

DOI: https://doi.org/10.30880/peat.2021.02.01.004
Received 13 January 2021; Accepted 01 March 2021; Available online 25 June 2021

Abstract: In the lack of systematic delivery of modern cooking fuels in developed countries, strategies have been adopted to use biomass residue that abound in most of these countries. This is meant to substitute of wood charcoal and thus limit forest harvesting for fuel purposes. For this cause, palm oil residue briquettes have been marketed as a safer substitute for wood charcoal for heating, cooking and other industrial applications in both urban and rural populations. The main objectives in this study are to determine the feasibility of palm kernel shell by comparing combustion properties of PKS sample briquettes with commercialized wood charcoal and to determine the most suitable binding agent mixture ratio in biofuel briquette. A laboratory experiment was conducted to determine the physico-chemical characteristics of the briquettes. Slow pyrolysis treatment was conducted in a furnace at 200 ℃, 400 ℃ and 600 ℃ respectively. In addition to mixing palm kernel shell bio-char (PKSB) with two different binders namely starch and NaOH. Results of the physical characterization of the briquettes were as follows, moisture content (16.64 % dry basis), ash content (45.19 %), fixed carbon (43.07 %), volatile matter (9.19 %) and calorific value (14.85 /kg). In this study, it is found that PKS sample treated with pyrolysed temperature of 600 ℃ together mixed with 5.00 % starch composition in biofuel briquette is the most suitable alternative for wood charcoal.

Keywords: Palm Kernel Shell, Biomass Residues, Slow Pyrolysis Treatment, Biofuel Briquettes

1. Introduction

Palm plantation is the most readily available source of biomass for Malaysia. After Indonesia, Malaysia is the world's second-largest producer of palm oil, and production continues to grow due to continuous palm plantation growth. A large amount of palm waste is produced in the palm plantation, such as oil palm frond (OPF), palm kernel shell (PKS), empty fruit brunch (EFB), palm trunk and mesocarp fiber [1]. Approximately 10.00 % of usable goods were made from palm oil trees and 90 per

*Corresponding author: nfikry@uthm.edu.my

cent from waste products [2].The shell fractions left after the nut was extracted after crushing at the Palm Oil mill are Palm Kernel shells. Kernel shells are fibrous and are conveniently handled straight from the production line to the end of use in large quantities. Palm kernel shells are carbonaceous solids formed by the production of palm oil fruit. Carbon-containing solids produce high-volume carbon elements and could be transformed by thermal reactions to carbon content as a source of heat energy.

Oil palm is the main crop in Malaysia that has transformed its farming and economic scenarios. This industry produces abundant solid biomass waste such as palm kernels shell (PKS), oil palm fronds (OPF), empty fruit brunch (EFB) and palm pressed fiber (PPF) and palm oil mill effluent (POME) which are readily used as a renewable source and as a useful organic material through various processes such as thermochemical [3]. There are over 400 palm oil mills in Malaysia and each of them generates a large amount of waste. However, there is a greater issue with the handling of oil palm waste. The solid biomass waste produced by the palm oil industry in Malaysia was estimated at approximately 75.61 million tons per year in 2015 [4] where it is a waste not used and can be catastrophic to the environment. The production of palm oil biomass waste is expected to be 85-110 million tons million tons per annum by 2020. In relation to waste management and greenhouse gas production from solid biomass, the increase in waste generation raises environmental sustainability challenges [4]. In order to find alternative to convert solid biomass waste from palm oil industry to wealth, palm kernel shell (PKS) has great potential to be source of energy (briquette) that is widely used especially in third world country.

Objectives for this study are to determine and study the feasibility of Palm kernel Shell and physico-chemical characterization. Moreover, to compare the combustion properties of briquette produced from carbonized PKS and wood charcoal by comparing combustion properties of palm kernel shell samples with wood charcoal. Furthermore, to determine and optimize suitable binding agent mixture ratio of PKSB to binders and improve the characteristics of briquettes including maintaining low votality, ash content, moisture content and higher fixed carbon and high calorific value.

2. Literature Review

2.1 Palm Kernel Shell

Palm kernel shell (PKS) is highly lignocellulose biogenic waste produced by raw palm oil processing where the shell pieces that were left after the nut was removed and crushed in the palm oil mill which are collected from the nut as residual waste. Oil palm is grown in plantations of rotary farming for around two to three decades, followed by removal and replanting [5]. In 2001, Indonesia and Malaysia produced an estimated value of 3.06 million metric tons. PKS is the hard part containing a palm kernel fruit nut, which contains palm kernel seeds [6].

2.2 Slow pyrolysis treatment

Pyrolysis requires rapid biomass heating and preserving for a given time non-condensable gases, solid chars and liquids in the absence of air or oxygen at the optimum temperature (pyrolysis temperature) [7]. The initial pyrolysis product consists of solid char and condensing gas. More condensable gas will break into liquid, char and non-condensable gasses (CO, CO_2, CH_2 and CH_4). This decomposition is caused partly by homogenous gas-phase reactions and partly by heterogeneous thermal reactions from the gas-solid phase. The condensable vapor is cracked into minor non-condensed permanent gas molecules like CO and CO_2 when the gas phase reactions are initiated. According to [7], pyrolysis process can be described such as in the equation 1.

$$C_nH_mO_p\ (Biomass) \xrightarrow{heat} \Sigma_{liquid}\ C_xH_yO_z + \Sigma_{gas}\ C_aH_bO_c + H_2O + C\ (char) \qquad Eq.\ 1$$

Slow pyrolysis define as in the absence of oxygen the biomass is slowly heated to relatively low temperatures (~400 ° C). Thus, the component in the vapor phase continue to react with each other while the residence time is too high in the range of 5 min to 30 min which results in the formation of solid char and liquid [8].

2.3 Binding agent

In order to hold the particles in the densified product, binding agent is required in the densified palm biomass. Application of the binders should be make after carbonization of the feedstock or during mixing of the feedstock. When low-pressure compaction is used, some biomass feedstock will not agglomerated except when the binding agent is added in the mixture of raw material. Two forms of binders, namely natural binders, and synthetic binders are used in briquette processing. The synthetic binders can then be further classified into two groups, which are as organic binder and inorganic binder. The organic binder, lignin, is considered to occur at moderate temperatures (150 °C-250 °C) [9] Organic binders are starch (maize, tapioca, cassava, and potato), paper and molasses, which were used most frequently in research. While, tar, biodiesel, caustic soda and calcium carbonate were the inorganic synthetic binder [10].

2.4 Biomass briquettes

The process of briquetting is the transformation of agricultural waste into easy-to-use, transport and store uniformly designed briquettes. The concept of briquetting is to use materials, which due to a lack of density are not available, and to compress them into solid fuel of convenient form that can be burnt like wood or charcoal [11]. In contrast to the initial waste, briquettes have improved physical and combustion properties. The main advantages of briquetting therefore include producing high-thermal efficient solid fuel, reducing waste volumes, having a low energy consumption for production and environmental conservation [11]. The raw material used for the briquetting process in this project is the palm kernel shell (PKS).

3. Methodology

3.1 Material and Equipment

Palm kernel shell (raw material) was collected in Bukit Pasir Palm Oil Mill, Tapioca starch (Synergy Food Processing Ind Sdn Bhd), sodium hydroxide, wood charcoal, fire starter (cock brand),Reverse osmosis water,Precision balance (Mettler, US), Oven (Memmert , US),Ball Milling Grinder (Kinematic, Switzerland),Laboratory Test Sieve 0.6 mm (Utest, Turkey), Laboratory Chamber Furnace (Protherm, Turkey), Neophrene filter adapter tube (mould) and Thermogravimetric Analyzer (Perkin Elmer, USA) .

SLOW PYROLYSIS TEMPERATURE

200℃ 400℃ 600℃

PKSB TO BINDER RATIO (Total 20g)

95:5 90:10 85:15

COMPACTION OF BRIQUETTES

CHARACTERIZATION OF BRIQUETTES

- Proximate analysis
- Calorific value
- Combustion characterization

WATER BOILING TEST (ADD 1 PIECE OF FIRE STARTER)

Burning rate Specific fuel consumption

SELECT BEST PKSB BRIQUETTES

Figure 1: Flowchart of experimental procedure showing temperature, PKSB-binder ratios and characterization of the briquettes produced

3.1 Sample preparation

Palm kernel shells was collected from Bukit Pasir Palm Oil Mill Muar, Johor. In this experiment, pyrolysis process of the palm kernel shell produced palm kernel shell bio-char (PKSB). Firstly, the moisture content was removed by sun dried the raw palm kernel shell for three days. Then, growth of fungus can be avoided by further drying in oven at temperature of 105 ℃ for 24 hours. After that, in order to improve surface area, binding and strength of the briquette sample, of raw palm kernel shells was ground and laboratory test sieve was used to sieve grinded PKS through 0.6 mm.

3.2 Slow pyrolysis process

The ground samples of palm kernel shells were heated in a furnace PLF series 140-160 (PROTHERM, turkey) to undergo pyrolysis process. The pyrolysis process was conducted under condition temperature of 200 ℃, 400 ℃ and 600 ℃ for 30 minutes. The carbonized samples were kept in a desiccator immediately after being taken out from the furnace and stored airtight container at room temperature until used.

3.3 Mixing bio-char with two different binders

In this process, the apparatus that are use involve 50 ml flat bottom beaker, weighing scale, a magnetic stirrer and crucible. There are two different binders use in this experiment, which are tapioca starch and sodium hydroxide (NaOH) at various percentage composition, which are 5.00 %, 10.00 % and 15.00 %. The palm kernel shells bio-char (PKSB) were mix together with tapioca starch or sodium hydroxide. The mass ratio composition are 95.00 % (PKSB) + 5.00 % (binder), 90.00 % (PKSB) + 10.00 % (binder) and 85.00 % (PKSB) + 15.00 % (binder) for total mass (20g) of the mixed material. For 5.00 % of binder in the PKSB-binder mixture, 1 g of the tapioca starch was prepared. Next, boil 10 ml of water in a container at 70 ℃. The tapioca starch powder was added into the boiling water and was mixed properly to get the starch gel. While the starch gel is still warm, 19 g of the PKSB (200 ℃) mixture was gradually added into the gel and mixed using a spatula until a thick (15 minutes), black compound was formed. . However, another 8 samples of carbonized PKS at 400 ℃ and 600 ℃ were prepared. These steps are repeated with another binder, which is sodium hydroxide. All the thick paste of the sample is manually pressed into neophrene tube molds.

3.4 Palm kernel shell briquetting process

The PKSB-binders mixture was poured in two-neoprene tube mold of top 37 mm OD x 31 mm, height 25 mm for briquetting the mixture manually for 18 samples. Two different samples were produced, which are sample (A), carbonized PKS powder plus starch as binding agent and Sample (B), carbonized PKS powder plus NaOH as binding agent. Next, the mixture of carbonized PKSB with binders were compressed manually by using pestle in a mold for 10 minutes. The two sample briquettes, which are sample A and B, were ejected from the mold after compression and allow staying for 5 minutes. The following tests are conducted on the briquettes after 3-4 days sun drying from the date of molding process conducted. Lastly, the briquette samples were kept in a vacuum-sealed bag to minimize moisture absorption from the surrounding humidity for further testing analysis.

Figure 2: Palm kernel shell briquettes for starch binder on the left and palm kernel shell briquettes for NaOH binder on the right

3.5 Calorific Value

The energy content of briquettes is determined by the heat value. A protocol for calorific values of generated briquettes using the Eq. 2 proposed by Demirbas (1997) where heating value is a function of FC and VM of the dry and ash-free coal s. It is seen that the calorific value is also a function of FC and VM for biomass fuel (Demirbas,1997).

$$Qv = 0.312(FC) + 0.1534(VM) \qquad \textit{Eq. 2}$$

Where:

Qv = Heating/ Calorific value (kJ/kg),

FC = Fixed carbon

VM = Volatile matter

3.6 Burning rate

Briquettes burn rate is assessed by measuring the weight of briquettes before combustion and after briquettes is totally burnt, Eq. 3 is used to calculate the burning rate consumption of the briquettes samples [12].

$$Burning\ rate = \frac{mass\ initial - mass\ final}{time\ taken} \qquad \textit{Eq. 3}$$

3.7 Specific fuel consumption

Basic fuel consumption was estimated using Eq. 4 during the water-boiling test:

$$Specific\ fuel\ consumption = \frac{mass\ initial - mass\ final}{volume\ initial - volume\ final} \qquad \textit{Eq. 4}$$

3.8 Proximate analysis

Proximate analysis test included the determination of volatile matter, ash content, fixed carbon and moisture content by using thermogravimetric analysis (TGA) under constant nitrogen gas, N flow (10 ml/min) at a heating rate of 10 °C/min.

4. Results and Discussion

4.1 Calorific value

The calorific value or high heating value (HHV) (MJ kg^{-1}) of the biomass samples as a function of fixed carbon (FC, wt %) and volatile matter (VM, wt %).

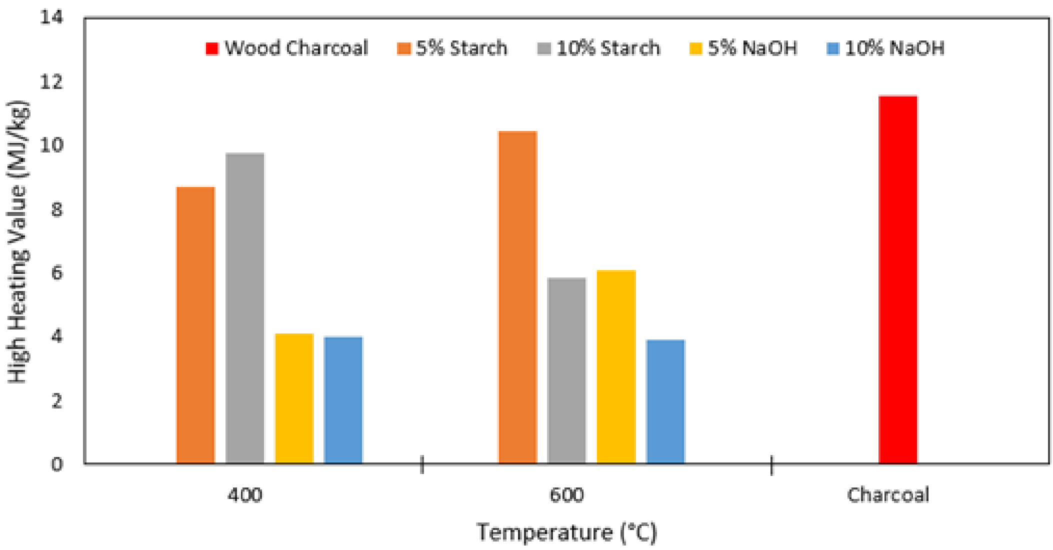

Figure 3: Graph of high heating value (MJ/kg) versus temperature (℃) and wood charcoal

Heat value or calorific value determines the energy content of a fuel. It is the property of biomass fuel that depends on its chemical composition and moisture content. The most important fuel property is its calorific or hhigh heating value [13]. The computed calorific value or high heating value for the palm kernel shell charcoal briquette sample 600 ℃ (5.00 % starch) was 10.45 MJ/kg while commercialized wood charcoal has 12.03 MJ/kg. This energy value can produce enough heat required for household cooking and small-scale industrial cottage applications. Thus, ratio composition in sample 600 ℃ (5.00 % starch) is more preferred compared to other samples to be biofuel briquettes.

4.2 Proximate analysis

Proximate analysis test included the determination of volatile matter, ash content, fixed carbon and moisture content.

4.2.1 Volatile matter

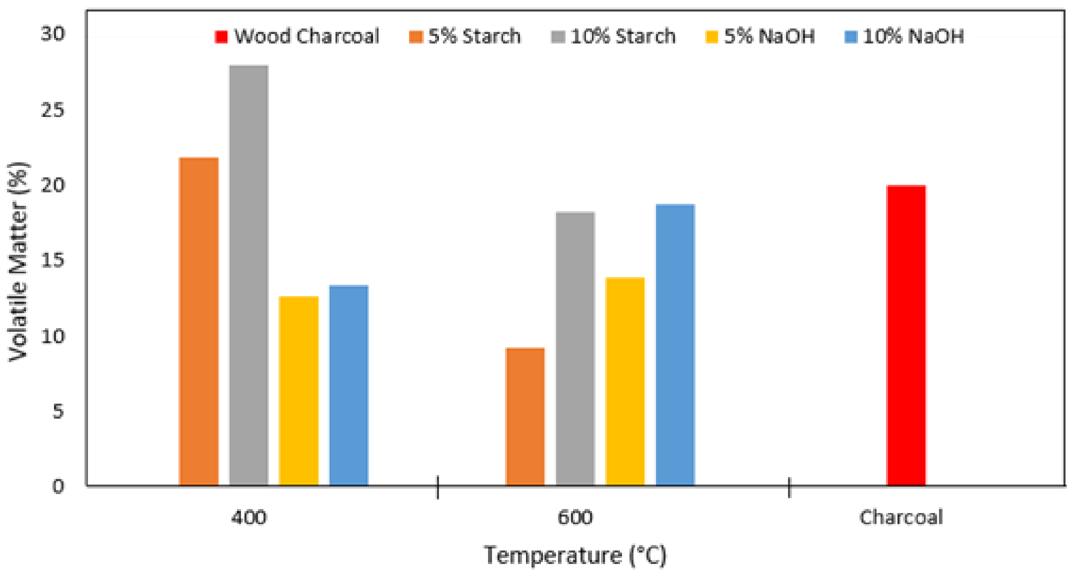

Figure 4: Graph of percentage volatile matter versus different temperature℃ and wood charcoal

A plot of the percentage volatile matter of samples was shown in Figure 4. The highest proximate analyse for the volatile matter of the palm kernel shell in this experiment is 27.92 % which is in samples 400 °C (10.00 % Starch). After slow pyrolysis treatment with the temperature 600 °C (5.00 % Starch) for 30 minutes, the samples obtained the least volatile matter content, which is 9.19 % in the briquette. This indicates that the release of volatile matter took place during pyrolysis treatment. In comparison, sample 600 °C (5.00 % Starch) has better volatile matter content rather than commercialized wood charcoal, which is 20.03 %. Thus sample 600 °C (5.00 % Starch) is more favor to be biofuel briquette.

4.2.2 Ash content

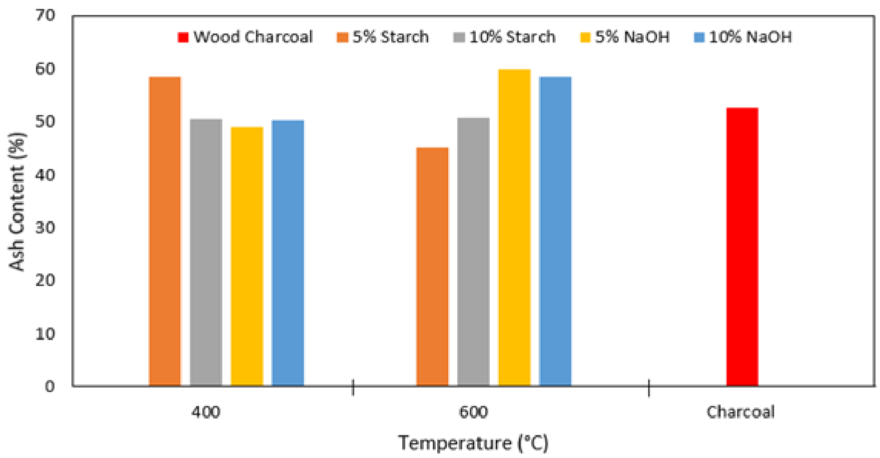

Figure 5: Graph of percentage of ash content versus temperature °C and wood charcoal

From Figure 5, the ash content showed significant higher value at the temperature 400 °C than that of 600 °C. Hence, the inorganic content has been removed during the raw material carbonization. According to [14], ash has a significant influence on the heat transfer to the surface of a fuel as well as the diffusion of oxygen to the fuel surface during char combustion. As ash is an impurity that will not burn, fuels with low ash content are better suited for thermal utilization than fuels with high ash content. Higher ash content in a fuel usually leads to higher dust emissions and affects the combustion volume and efficiency. According to [15], the higher the fuel's ash content, the lower is its calorific value.

4.2.3 Moisture content

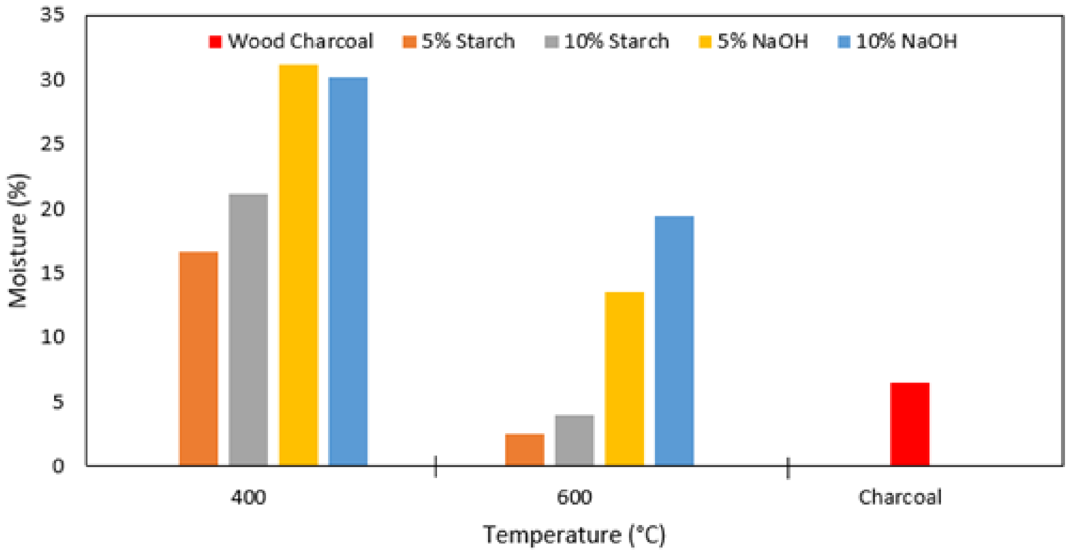

Figure 6: Graph of percentage of moisture content versus temperature °C and wood charcoal

From Figure 6 the moisture content in the samples has increased and decreased as the temperature increase. According to the graph of percentage of moisture versus temperature, a sample 400 °C (5.00 % NaOH) has the highest moisture content in the briquette while sample 600 °C (5.00 % Starch) has the lowest moisture content in the briquette. Thus, sample with starch binding agent is more preferred in the quality of biofuel briquette. However, commercialize wood charcoal sample has 6.50 % moisture content in the briquette. Then, sample 600 °C (10.00 % Starch) has near value of moisture content which is 16.64 % compare with commercialize wood charcoal sample. This indicates that the total energy that is needed to bring a briquette up to its pyrolytic temperature is dependent on its moisture content that affects the internal temperature within the briquette due to endothermic evaporation [16]. According to [13], moisture content is one of the main parameters that determine briquette quality. A lower moisture content of briquettes implies a higher calorific value.

4.2.4 Fixed carbon

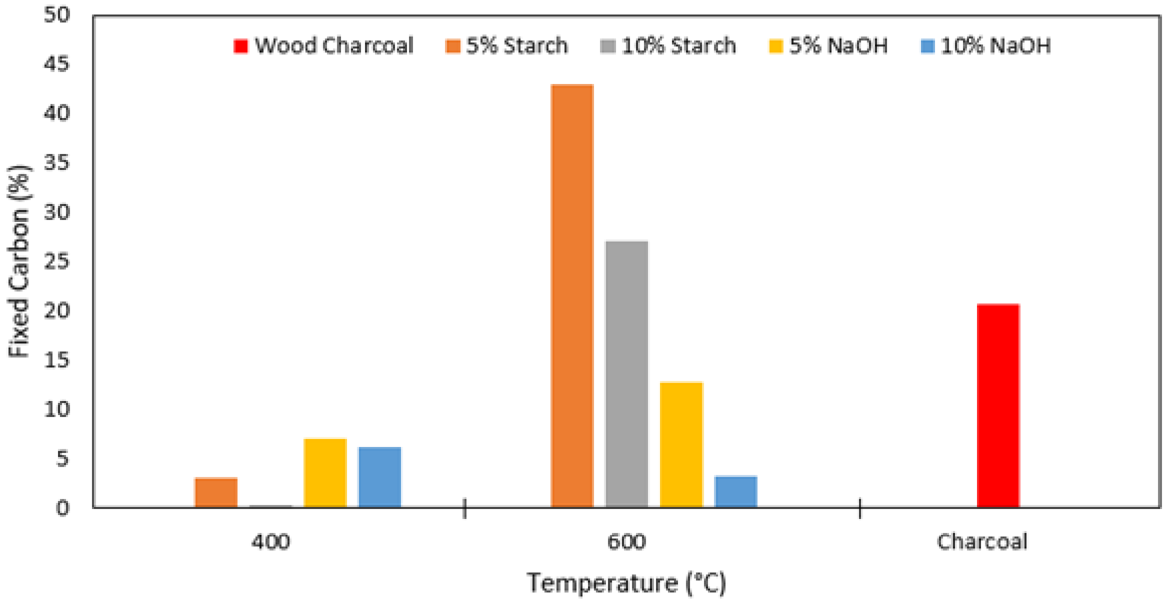

Figure 7: Graph of percentage of fixed carbon content versus temperature °C and wood charcoal

According to the Figure 7, sample 600 °C (5.00 % starch) has the highest value of fixed carbon that is 43.07 % while the lowest value 0.42 % for sample 400 °C (10.00 % starch). The fixed carbon of the briquette, which is the percentage of carbon (solid fuel) available for char combustion after volatile matter is distilled off, was determined to be 20.71 % for commercialized wood charcoal. Thus, sample 600 °C (5.00 % starch) is suitable to be an alternative charcoal. Fixed carbon gives a rough estimate of the heating value of a fuel and acts as the main heat generator during burning [16].

4.2.5 Specific fuel consumption

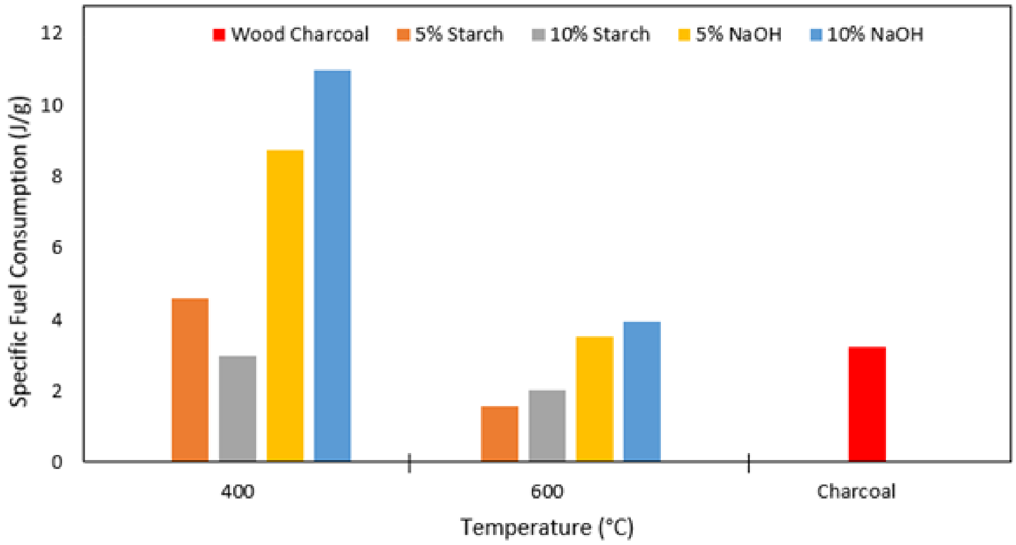

Figure 8: Graph of specific fuel consumption versus temperature °C and wood charcoal

Comparison of the performance between the specific fuel consumption of the briquettes showed that briquette sample 600 °C with 5.00 % starch is 1.57 J/g with the lowest specific fuel consumption while the highest specific fuel consumption is 10.97 J/g which is sample 400 °C (10.00 % NaOH). Thus, the specific fuel consumption which measures the quantity of the fuel required to boil water shows that 600 °C with 5.00 % starch composition will be more economical than the other samples followed by 2.02 J/g for sample 600 °C (10.00 % starch) and 2.98 J/g for sample 400 °C (10.00 % starch).

4.2.6 Burning rate

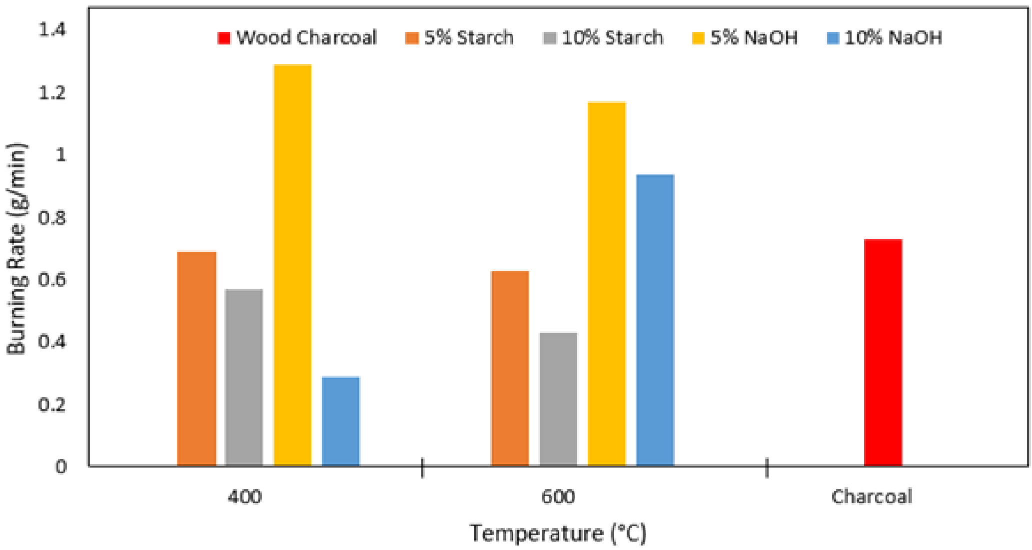

Figure 9: Graph of burning rate versus temperature °C and wood charcoal

From Figure 9, the burning content in the most samples has increased as the temperature increase. The burning rate values of the briquettes obtained decreased with increased binder proportion. The implication of this observation is that more fuel might be required for cooking with briquettes produced from 5.00 % binder than 10.00 % binder. The briquettes produced from 10.00 % binder level had the lowest burning rate. The effect of binder on the burning rate of the palm kernel shell briquettes with

NaOH as a binding agent. In this study, discovered that the binding of the palm kernel shell and NaOH prevented the fast burning of the briquettes.

5. Conclusion

The results of this study show that sample 600 ℃ with 5.00 % starch is more suitable to be an alternative of wood charcoal since it proximate analysis shows the highest fixed carbon and low ash content and moisture content compared with other sample and also has highest calorific value. In comparison, combustion properties such as specific fuel consumption show that sample 600 ℃ with 5.00 % starch consume low fuel when burning which is 1.57 J/g compare with commercialized wood charcoal (3.25 J/g). Thus, starch-binding agent (organic) at pyrolysis temperature 600 ℃ with 5.00 % ratio composition binding agent is way more suitable and sustainable to be an alternative of charcoal. The concept of waste to wealth has been successfully implemented in this study where waste palm kernel shell from palm oil industry could be converted into biofuel briquettes (new product).

Acknowledgement

The authors would like to thank the Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia for its support

References

[1] Abdullah, N., & Sulaiman, F. (2013). The oil palm wastes in Malaysia. Biomass now-sustainable growth and use, 1(3), 75-93.

[2] Board, M. P. O. (2011). Overview of the Malaysian oil palm industry.

[3] Awalludin, M. F., Sulaiman, O., Hashim, R., Nadhari, W. N. A. W. 2015. An overview of the oil palm industry in Malaysia and its waste utilization through thermochemical conversion, specifically via liquefaction. Renewable and Sustainable Energy Reviews, 50, 1469-1484

[4] Oseghale, S. D., Mohamed, A. F., & Chikere, A. O. (2017). Status Evaluation of Palm Oil Waste Management Sustainability in Malaysia. OIDA International Journal of Sustainable Development, 10(12), 41-48.

[5] Afolalu, S.A., E.Y. Salawu, I.P. Okokpujie, A.A. Abioye and O.P. Abioye et al., 2017. Experimental analysis of the wear properties of carburized HSS (ASTM A600) cutting tool. Int. J. Applied Eng. Res., 12: 8995-9003.

[6] Yusuf, I.T. and Y.A. Jimoh, 2012. Palm kernel shell waste recycled concrete road as cheap and environmental friendly freeway on very poor subgrades. Sci. J. Civil Eng. Architect., Vol. 2012

[7] Basu, P. (2013) .Biomass gasification, pyrolysis and torrefaction : Practical design and theory (pp 147-159). Elsevier Science & Technology. Retrieved from https://ebookcentral-proquest-com.ezproxy.uthm.edu.my

[8] Jahirul, M. I., Rasul, M. G., Chowdhury, A. A., & Ashwath, N. (2012). Biofuels production through biomass pyrolysis—a technological review. Energies, 5(12), 4952-5001.

[9] Faizal, H. M., Latiff, Z. A., and Mohd Iskandar, M. A. 2015. Characteristics of Binderless Palm Biomass Briquettes with various Particle Sizes. Jurnal Teknologi. 77(8): 1-5

[10] Ugwu, K., and Agbo, K. (2013). Evaluation of binders in the production of briquettes from empty fruit bunches of Elais Guinensis. International Journal of Renewable and Sustainable Energy. 2(4): 176-179

[11] El Haggar, S. (2010). Sustainable industrial design and waste management: cradle-to-cradle for sustainable development. pp 227-230. Academic Press.

[12] Onuegbu,T.U. (2010). Improving Fuel Wood Efficiency in Rural Nigeria (A case of Briquette Techonology).International Journal of Chemistry in Nigeria.Vol.3 (4) Pp 35-39-43.

[13] Aina, O. M., Adetogun, A., & Iyiola, K. A. (2009). Heat energy from value-added sawdust briquettes of albizia zygia. Ethiopian Journal of Environmental Studies and Management, 2(1).

[14] Kim, H. J., Lu, G. Q., Naruse, I., Yuan, J., & Ohtake, K. (2001). Modeling on combustion characteristics of biocoalbriquettes. J. Energy Resour. Technol., 123(1), 27-31.

[15] Shao, Y., Wang, J., Preto, F., Zhu, J., & Xu, C. (2012). Ash deposition in biomass combustion or co-firing for power/heat generation. Energies, 5(12), 5171-5189.

[16] Akowuah, J. O., Kemausuor, F., & Mitchual, S. J. (2012). Physico-chemical characteristics and market potential of sawdust charcoal briquette. International Journal of Energy and Environmental Engineering, 3(1), 20.