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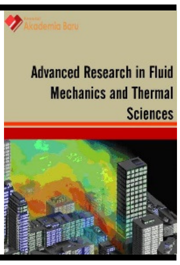

Torrefaction of pulverized empty fruit bunch and polyethylene plastics waste mixture

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ABSTRACT

The combustion properties of torrefied mixture of empty fruit bunch (EFB) and polyethylene (PE) plastics were investigated experimentally, for weight ratio of 95:5 (EFB: PE) and 90:10. The mixture samples were obtained from briquettes that were produced under various briquetting temperatures (150°C-190°C). The torrefaction was performed at constant temperature of 250°C and at constant nitrogen flow rate of 1 l/min. Generally, it can be said that the combustion properties such as calorific value and moisture content fulfil the minimum requirement stated by standard for commercial briquette (DIN51731). In addition, it can be said that the effect of mixture composition on the combustion properties is stronger than the effect of briquetting temperature.

Keywords:
Torrefaction, Empty fruit bunch (EFB), Plyethylene (PE) plastics, Vehicle system

1. Introduction

The climate change has spurred the transformation from the high energy dependence on fossil fuel to inexhaustible renewable energy (solar, wind, mini hydro and biomass) [1]. Renewable energy sources are abundant in Malaysia, the significant ones are biomass and solar energy [2]. Oil palm plantations are being actively cultivated and harvested, that cover close to five million hectares for year 2011 [3]. As a result, abundant palm biomass residues are produced during the processing of fresh fruit bunch (FFB), such as shell, mesocarp fibre and empty fruit bunch (EFB). Due to this scenario, it is inevitable to harness these bioenergy sources, in order to prevent from just being dumped as waste materials.

Briquetting is one of densification methods which is able to produce the product with higher energy content per unit volume. In addition, this technique becomes a solution for difficult handling

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and expensive transportation procedures [4]. Besides, the products of gasification of briquettes also have potential to be used for vehicle system [5]. The briquettes that contain various types of palm biomass have been introduced, with the aim to utilize such bioenergy sources effectively. The first attempt to convert these palm residues into solid fuels was successfully performed more than a decade ago, in which it contains mesocarp fibre and shell with starch as a binding agent [6]. Then, six years later, a technique of pulverizing palm biomass has been introduced to produce binderless briquette [7]. In the following years, several other efforts in making briquette were performed to utilize the massive production of residues during the oil extraction process from FFB, that are mesocarp fibre [4,8]. Based on these previous studies, it can be concluded that the heating values of briquettes produced are very close or slightly higher than that of commercial briquette.

Torrefaction is a thermal decomposition of biomass in the absence of oxygen. In addition to the enhancement of energy density and hydrophobic nature of the biomass, grindability, gasification potential and future prospects as a solid fuel are improved due to the modified structure [9]. Principally, the fuel properties of torrefied biomass are significantly influenced by torrefaction temperature, torrefaction time, and type of biomass. Torrefaction of palm biomass has been performed by [10] for empty fruit bunch fibre, mesocarp fibre and shell [10]. They have concluded that mesocarp fibre and shell exhibit excellent energy yield that is higher than 95%. Meanwhile, EFB demonstrates poor energy yield of 56%.

However, the fast growing demand requires the maximum utilization and recovery of energy [1,11]. In this case, the combination of torrefaction and densification of palm biomass is an attractive option for coping with the ever increasing energy demand. One of the earliest studies on palm biomass briquettes produced by combination technique was performed by Na et al. [12]. Based on their investigation on performance of pellets made of torrefied mesocarp fibre, they have concluded that the torrefaction temperature has more significant effect on the energy yield if compared to the reaction time. The study on densified palm biomass produced from the combination technique has also been performed by Nyakuma et al. (2015) [9]. Nyakuma et al. (2015) had successfully performed torrefaction on EFB pellets and they obtained a solid uniform fuel with improved physical and thermochemical properties. They found that the heating value of EFB pellets increased from 17.57 MJ/kg (without torrefaction) to 26.24 MJ/kg after being torrefied at temperature of 300°C [9].

The other ways to maximize the energy utilization is by mixing the biomass with plastics waste when making briquette, such as performed by [13,18]. Recently, Zannikos et al. have produced briquettes which contain mixture of sawdust/straw and polyethylene plastics waste. They found that the calorific values of biomass briquettes generally increase due to the plastics waste addition [13]. Based on their study, generally it can be said that the addition of polyethylene plastics waste to the biomass briquette is an attractive option for coping with the fast growing energy demand scenario. Before their study, Kers et al. (2010) have produced briquettes made of refuse derived fuel (RDF), which consists of mixture of municipal waste (38% wood chips from soft wood, 45% disintegrated carton waste, 11% disintegrated PET bottles and 6% textile waste [14].

In the present study, torrefaction of pieces that contain palm biomass (EFB) and polyethylene (HDPE) plastics waste was conducted to understand the combustion properties of the mixture after such treatment. The benchmark used to evaluate the combustion properties of the mixture is DIN51731, which is a standard requirement for making commercial briquette.

2. Methodology

2.1. Proximate analysis

In the present study, empty fruit bunch (EFB) fibre and polyethylene (PE) plastics were used as raw materials. The EFB fibre was obtained from Felda Lok Heng, Kota Tinggi, Johor while the PE plastics were purchased from a local supplier. The EFB fibres were ground and sieved into small particles size (<500µm). Meanwhile, the PE plastics were shredded and sieved into small tiny particles (1mm to 3.35mm). Proximate analysis for the raw materials and pieces of mixture that contain pulverized EFB and PE plastics was performed to determine the combustion properties. Proximate analysis was conducted based on American Society for Testing and Materials (ASTM) standards. Table 1 shows the standards used for the proximate analysis of the raw materials and the pieces produced. Meanwhile, Table 2 shows the results of proximate analysis for the raw materials (EFB and PE plastics). Based on Table 2, the moisture content for the raw materials used in the present study is found to fulfil the minimum requirement for making commercial briquette as stated by DIN51731(moisture content<10%).

Table 1
Standard Used for Proximate Analysis

Properties	**Standard Used**
Moisture Content	ASTM D3173
Volatile Matter	ASTM D3175
Ash Content	ASTM D3174

Table 2
Results of Proximate Analysis for EFB and PE Plastics

	EFB	**Polyethylene Plastics**
Fixed Carbon (%)	14.00	0.0
Moisture Content (%)	7.00	0.57
Volatile Matter (%)	75.50	92.37
Ash Content (%)	3.50	7.05

2.2. Thermogravimetric (TGA) analysis

TGA analysis was performed in the present study to characterize the thermal decomposition behaviour of pieces of mixture that contain pulverized EFB and PE plastics. Based on the comparison with behaviour of pieces of 100% EFB, the starting temperature for devolatization of both EFB and PE plastics can be obtained. TGA analysis was performed by PerkinElmer Thermogravimetric Analyzer (model TGA 4000). The operating condition for TGA analysis conducted is similar with that of previous study [16]. The heating rate was set to 10^{o}C/min while nitrogen with flow rate of 25 ml/min was used as sweep gas.

2.3. Determination of gross calorific value

Gross calorific values of raw materials and the pieces contain pulverized EFB and PE plastics are determined by using a bomb calorimeter, model LECO AC350 located at Combustion Laboratory, Faculty of Mechanical Engineering, Universiti Teknologi Malaysia (UTM). The result of the test for the raw materials is shown in Table 3. Based on Table 3, it can be said that the calorific value for EFB is lower than the minimum requirement as stated by DIN51731 (17500kJ/kg). However, the calorific value of PE plastics is much higher than the benchmark DIN51731. Therefore, it is worthwhile to utilize the PE plastics waste as energy source in the form of briquette.

Table 3
Gross Calorific Value of Raw Materials

Material	Average Calorific Value (kJ/kg)
EFB Fibre	16131
Polyethylene Plastics	40791.50

2.4. Torrefaction of mixture

In the present study, the torrefaction was performed for the pieces from homogeneous briquettes that contain pulverized EFB and PE plastics with weight ratio of 95:5 and 90:10. Here, the experimental setup for the production of the briquette has been illustrated in the previous study [15]. The pieces were obtained from the briquettes after the test of compressive strength [15]. Two types of temperature were involved; briquetting temperature and torrefaction temperature. The variable parameter was briquetting (densification) temperature (150°C,170°C and 190°C) while the torrefaction temperature was set constant at 250°C. In this case, the effect of briquetting temperature on the combustion properties of the torrefied mixture was investigated.

The torrefaction was performed by experimental setup as shown in Fig. 1. The internal diameter of the reactor was around 10cm. The sensor of type-K thermocouple was used to measure the temperature near the specimen (vertical distance about 5mm from the specimen). The temperature controller was used to maintain the torrefaction temperature at 250°C. Initially, the pieces of the briquettes were placed on the mesh holder and were put into the reactor. Then, the reactor was purged for 1 hour with nitrogen to remove air from the tank and to prevent the contact between the specimen and the air. Then, the specimen was torrefied at desired temperature (250°C) for 30 minutes. Then, the specimen was allowed to cool at room temperature before it was taken out from the reactor. Throughout the experiment, the flow rate of nitrogen was set to 1 L/min.

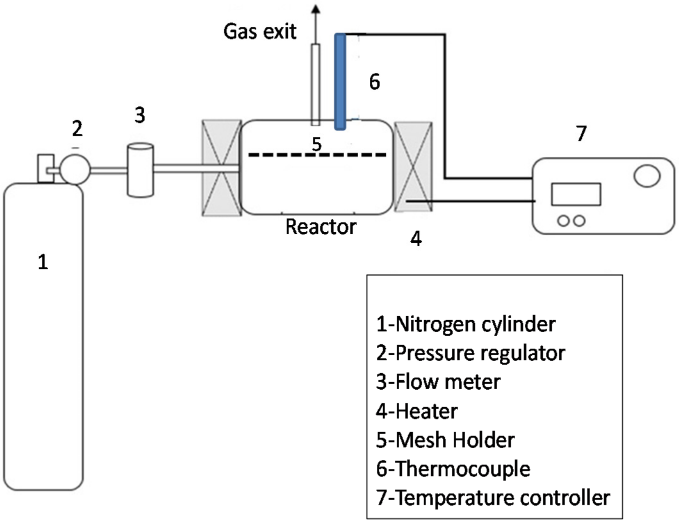


Fig. 1. Experimental setup for torrefaction

3. Results and discussion

In this section, the combustion properties of the pieces that contain pulverized EFB and PE plastics were investigated. The comparison with standard requirement DIN51731 was also performed where necessary.

3.1. Combustion properties

Figure 2 shows the images of pieces that contained mixture of EFB fibre and PE plastics for the briquetting temperature of 190°C and weight ratio of 90:10 (EFB: PE plastics). Based on the observation, the colour of the pieces change to dark brownish after torrefaction at 250°C. In addition, the blue colour can still be observed, that represents the PE plastics. Based on thermogravimetric analysis (TGA) analysis performed with operating condition similar as previous study [16], the devolatization of EFB fibre already occurs at the present torrefaction temperature (250^{o}C). On the other hand, PE plastics still is not decomposed yet. This phenomenon is clearly illustrated by Fig. 3. Fig. 3 demonstrates that the starting temperature for devolatization of EFB and PE plastics are around 191^{o}C and 441^{o}C, respectively.

(a) Before **(b) After**

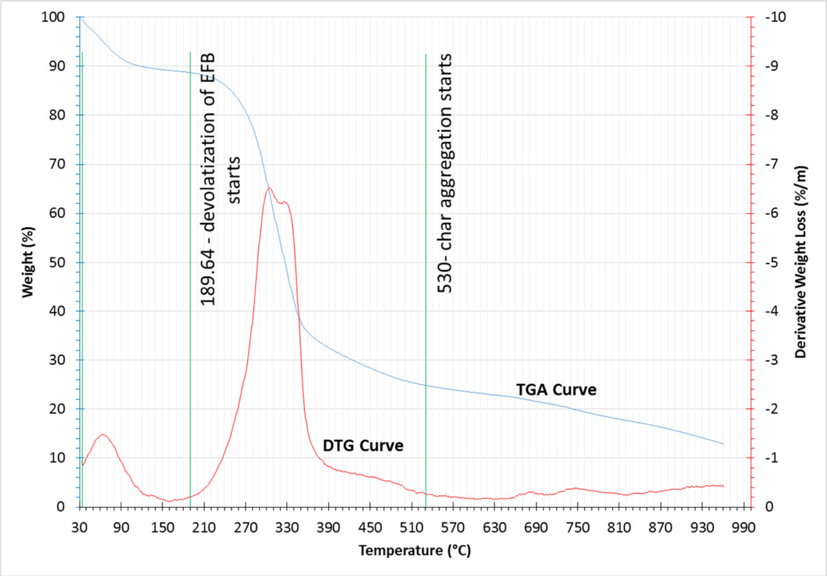
Fig. 2. Image of pieces (before and after torrefaction)

Figure 4 shows the results for calorific value of the mixture after torrefaction at 250°C, for various briquetting temperatures. Based on the Fig. 4, it can be said that all values fulfil the requirement stated by benchmark DIN51731 (>17500 kJ/kg). The figure demonstrates that regardless of briquetting temperature, the calorific values of the pieces with weight ratio of 90:10 (EFB: PE) are higher than that of 95:5. This is mainly due to the very high calorific value of polyethylene (PE) plastics. Fig. 4 also elucidates that calorific value of the torrefied mixture is strongly affected by mixture composition, rather than the temperature used during briquetting.

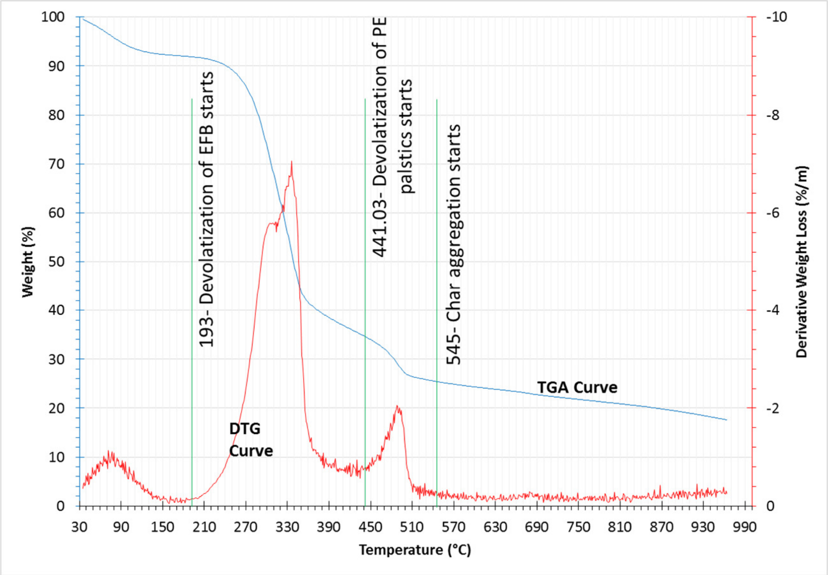
During torrefaction in the present study, mass loss occurs due to the drying, heating and partial devolatization process [16]. Therefore, mass yield is an important characteristic to determine the mass that remained after torrefaction. Here, mass yield (y_{mass}) is obtained from the following equation [17],

$$y_{mass} = (\textit{mass after torrefaction/mass of sample before torrefaction}) \times 100 \qquad (1)$$

Figure 5 shows the mass yield of the mixture (EFB and PE plastics) for various briquetting temperatures. The figure demonstrates the mass yield fluctuates within the range of 69% to 73% regardless of briquetting temperatures, thus reveal the independence of mass yield on the temperature used for making briquette. In addition, the figure also shows that the mass yield of the mixture with weight ratio 90:10 is higher than the mass yield of mixture ratio of 95:5. The main reason is due to the slower rate of devolatization when more PE plastics exist in the mixture.



(a) EFB fibre



(b) Mixture of EFB and PE plastics (weight ratio of 90:10) produced at briquetting temperature of 190°C

Fig. 3. TGA/DTG curve for (a) EFB fibre and (b) mixture of EFB and PE plastics

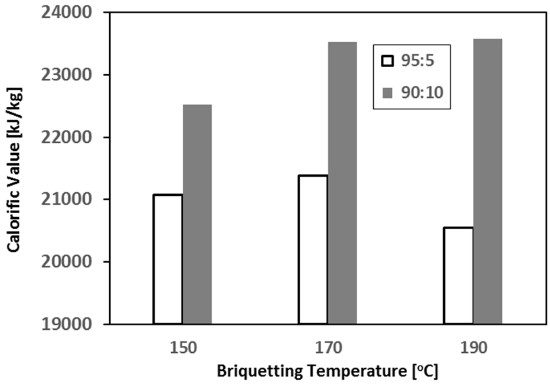


Fig. 4. Results of calorific values after torrefaction

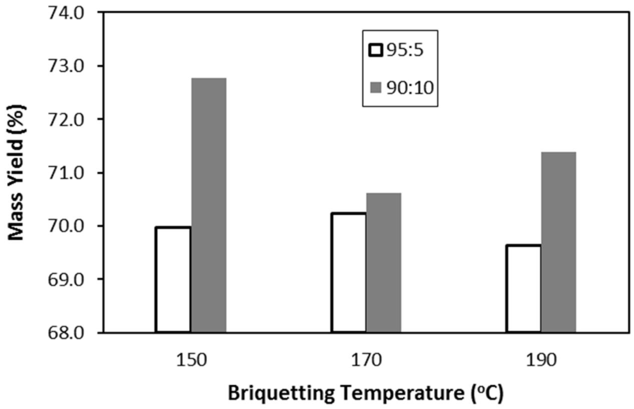


Fig. 5. Results of mass yield after torrefaction

The results of the mass yield obtained previously is then used to determine the energy yield. The energy yield (y_{energy}) is determined by the Equation (2) as follows [17],

$$y_{energy}=y_{mass}\times(\textit{calorific value of torrefied product/calorific value of sample before torrefaction})\ x\ 100 \quad (2)$$

Figure 6 shows the results of energy yield for various briquetting temperatures. The figure demonstrates that the values are within the range of 82-85%. However, the energy yield for the case of ratio 95:5 and briquetting temperature of 190°C is relatively lower than those for the other cases. This is mainly due to the lowest calorific value after torrefaction and lowest mass yield for such case, as demonstrated by Fig. 4 and Fig. 5, respectively.

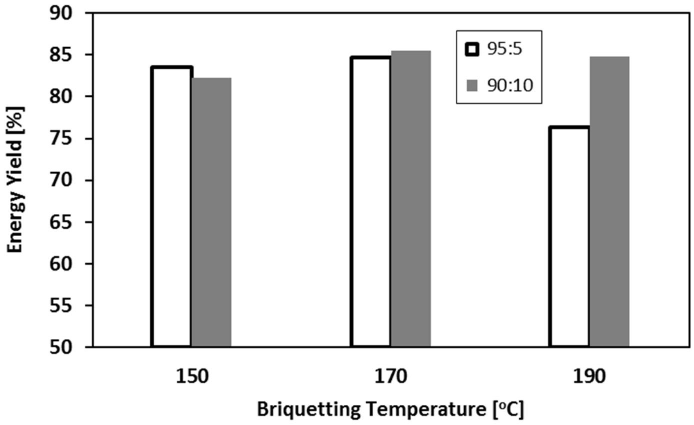


Fig. 6. Results of energy yield after torrefaction

Table 4 shows the results of proximate analysis of the torrefied mixtures. The results demonstrate that the moisture contents of the pieces of mixture fulfil the requirement as stated by DIN51731 (<12%). However, the ash content exceeds the minimum requirement (0.7%). Based on the table, it can be said that the volatile matter of the mixture with weight ratio of 90:10 (EFB: PE) are higher compared to that of the other mixture (weight ratio 95:5) while the fixed carbon is lower. This is mainly due to the very high volatile matter content of PE plastics, as shown by Table 2. In addition, regardless of briquetting temperature, it can be said that the results of proximate analysis for the same weight ratio are close to each other, with small fluctuation.

Table 4
Results of Proximate Analysis (After Torrefaction)

Briquetting Temperature [°C]	150	170	190	150
Weight Ratio (EFB:PE Plastics)	90:10			95:5
Moisture Content (%)	5.90	5.00	6.53	5.31
Volatile Matter (%)	69.25	69.70	71.26	64.90
Fixed Carbon (%)	20.56	20.04	18.05	25.64
Ash Content (%)	4.29	5.26	4.16	4.15

4. Conclusion

The investigation on combustion properties of the mixture of empty fruit bunch (EFB) and polyethylene plastics has been performed. In general, it can be said that all values of calorific value and moisture content fulfill the requirement for making commercial briquette (DIN51731). However, the values of ash content exceed the minimum requirement as stated by the standard.

In the present study, it can be said that the mixture composition plays a significant role in affecting the calorific value, mass yield, volatile matter and fixed carbon content, rather than the temperature used for making the briquettes.

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References

[1] Mekhilef, Saad, Meghdad Barimani, Azadeh Safari, and Zainal Salam. "Malaysia's renewable energy policies and programs with green aspects." *Renewable and Sustainable Energy Reviews* 40 (2014): 497-504.

[2] Shafie, S. M., T. M. I. Mahlia, H. H. Masjuki, and A. Andriyana. "Current energy usage and sustainable energy in Malaysia: a review." *Renewable and Sustainable Energy Reviews* 15, no. 9 (2011): 4370-4377.

[3] Zwart, Dr. "Opportunities and challenges in the development of a viable Malaysian palm oil biomass industry." *Journal of Oil Palm, Environment and Health (JOPEH)* 4 (2013): 41-46.

[4] Sing, Chin Yee, and Mohd Shiraz Aris. "An experimental investigation on the handling and storage properties of biomass fuel briquettes made from oil palm mill residues." *Journal of Applied Sciences* 12, no. 24 (2012): 2621-2625.

[5] FanBin, Meng, Yang TianHua, Liu Jiankun, Wang GuiLu, Li XiaoWei, and Zhang DaLei. "Experimental study on stalk briquette gasification producer gas for vehicle fuel." *Kezaisheng Nengyuan/Renewable Energy Resources* 26, no. 6 (2008): 48-51.

[6] Husain, Z., Z. Zainac, and Z. Abdullah. "Briquetting of palm fibre and shell from the processing of palm nuts to palm oil." *Biomass and Bioenergy* 22, no. 6 (2002): 505-509.

[7] Nasrin, A. B., A. N. Ma, Y. M. Choo, S. Mohamad, M. H. Rohaya, A. Azali, and Z. Zainal. "Oil palm biomass as potential substitution raw materials for commercial biomass briquettes production." *American Journal of Applied Sciences* 5, no. 3 (2008): 179-183.

[8] Faizal, H. M., Z. A. Latiff, Mazlan A. Wahid, and A. N. Darus. "Physical and combustion characteristics of biomass residues from palm oil mills." In *New Aspects of Fluid Mechanics, Heat Transfer and Environment: Proceedings of the 8 th International Conference on Heat Transfer, Thermal Engineering and Environment*, pp. 20-22. 2010.

[9] Nyakuma, Bemgba Bevan, Arshad Ahmad, Anwar Johari, Tuan Amran Tuan Abdullah, and Olagoke Oladokun. "Torrefaction of Pelletized Oil Palm Empty Fruit Bunches." *arXiv preprint arXiv:1505.05469* (2015).

[10] Uemura, Yoshimitsu, Wissam N. Omar, Toshio Tsutsui, and Suzana Bt Yusup. "Torrefaction of oil palm wastes." *Fuel* 90, no. 8 (2011): 2585-2591.

[11] Economic Planning Unit, EPU (2010), Tenth Malaysia Plan 2011-2015, Chapter 6-Building an Environment that Enhances Quality of Life, Prime Minister’s Department, Putrajaya. Retrieved on 04/05/2016 from: http://www.epu.gov.my/epu-theme/RMKE10/img/pdf/en/chapt6.pdf

[12] Na, Byeong-Ill, Young-Hun Kim, Woo-Seok Lim, Soo-Min Lee, Hyoung-Woo Lee, and Jae-Won Lee. "Torrefaction of oil palm mesocarp fiber and their effect on pelletizing." *Biomass and Bioenergy* 52 (2013): 159-165.

[13] Zannikos, F., S. Kalligeros, G. Anastopoulos, and E. Lois. "Converting biomass and waste plastic to solid fuel briquettes." *Journal of Renewable Energy* 2013 (2012).

[14] Kers, Jaan, Priit Kulu, Aare Aruniit, Viktor Laurmaa, Peter Križan, Lubomir Šooš, and Ülo Kask. "Determination of physical, mechanical and burning characteristics of polymeric waste material briquettes." *Estonian Journal of Engineering* 16, no. 4 (2010): 307-316.

[15] Faizal, H. M., M. Shafiq M. Nazri, Md. Mizanur Rahman, S. Syahrullail and Latiff, Z. A. "Development of Palm Biomass Briquettes with Polyethylene Plastic Waste Addition." *Jurnal Teknologi* 78, no. 9 (2016): 69-75.

[16] Nyakuma, B.B., Johari, A., Ahmad, A., and Abdullah, T.A.T. "Thermogravimetric Analysis of the Fuel Properties of Empty Fruit Bunch Briquettes." *Jurnal Teknologi* 67, no. 3 (2014): 79-82.

[17] Bridgeman, T. G., J. M. Jones, I. Shield, and P. T. Williams. "Torrefaction of reed canary grass, wheat straw and willow to enhance solid fuel qualities and combustion properties." *Fuel* 87, no. 6 (2008): 844-856.

[18] H. Mohd Faizal, Z. A. Latiff, M. A. Mohd Iskandar and M. S. Mohamad Nazri. "Physical Characteristics of Briquettes Contain Mixture of Pulverized Empty Fruit Bunch and Polyethylene Plastics." *Journal of Advanced Research in Materials Science* 11, no. 1 (2015): 1-7.