Dutse Journal of Pure and Applied Sciences (DUJOPAS) Vol. 4 No. 1 June 2018

INFLUENCE OF TEMPERATURE ON THE PROPERTIES OF TORREFIED OIL PALM EMPTY FRUIT BUNCHES

Safana, A.A Department of Physics,
Faculty of Science,
Federal University Dutse
Jigawa State, Nigeria

Sabiu S.A Department of Physics,
Faculty of Science,
Federal University Dutse
Jigawa State, Nigeria.

Adamu, B.I Department of Physics,
Faculty of Science,
Federal University Dutse
Jigawa State, Nigeria.

Mohammad S. I Department of Physics,
School of Science,
Federal College of Education,
Kano, Nigeria.

Hussaini Yusuf Department of Physics,
Faculty of Science,
Kano State University of Science and
Technology Wudil,
Kano State, Nigeria.

.

Abstract

This study assessed the impact of torrefaction temperature on the torrefaction products yield, energy yield and properties of the solid biomass obtained. Oil palm empty fruit bunches (EFB) werecollected from oil palm mill and torrefied at a constant heating rate of 10 $^{o}Cmin^{-1}$, for 30 min at varying temperatures of 200, 250 and 300 ^{o}C. It was found that as the temperature increased *high gas and liquid were obtained against the solid product. The energy yield observed were 91, 94 and 99 % for 200, 250 and 300 °C, respectively.The maximum calorific value, fixed carbon and carbon content of 20.96 MJkg⁻¹, 17.89 wt%, and 46.97 wt% were achieved at torrefaction temperature of 300 °C. The improvement in the calorific value, fixed carbon, and the carbon content was due to the moisture, volatile matter and hydrogen content removal in the biomass. Therefore, torrefaction within a temperature range of 200-300 °C could be described as advanced drying method to improve the quality of biomass.*

Keywords: palm oil; biomass; EFB; torrefaction; temperature

INTRODUCTION

Solar, wind, geothermal, hydroelectric and biomass energies are the most common renewable energy sources available. Among these renewable energies, biomass energy is the largest and an essential one that has been employed in both developed and developing countries(Abdullah *et al.* 2016). Biomass is formed when carbon dioxide and solar energy (sunlight) with water are mixed via photosynthesis. However, burning of biomass results in the release of carbon dioxide into the atmosphere accompanied by the conversion of stored chemical energy in the biomass into thermal energy (Chen *et al*. 2011; Abdullah *et al.* 2017). Biomass supplies a renewable energy source that could considerably improve the environment, economy and energy security through reducing the burning of fossil fuels, emission of greenhouse gasses (GHG) and environmental pollution. Biomass can be used to generate heat and power for industry and domestic purposes.

However, direct combustion of biomass is not the best way to use it as a burning fuel. Some processes can be used to upgrade the standard of biomass for better and proper application. Some of these processes include dewatering and drying, pulverization or grinding, and densification process such as pellets. The dewatering and drying is a process whereby the moisture content of biomass is removed, thus improving the heating value of the biomass material. Size reduction (pulverization) is known as a process for expanding the biomass surface per unit mass, which will make the biomass more conducive to the reaction of the material during combustion, gasification or pyrolysis. The densification process is a means of reducing the volume of biomass by compaction which can make the biomass storage and transportation much simple. Besides the above-mentioned conventional pretreatment, there is also another significant and efficient process for upgrading biomass as a fuel known as torrefaction (Chen *et al*. 2011). Torrefaction can be described as a thermochemical process carried out in the temperature range of 200 to 300 °C under an oxygen-free condition with a purpose to upgrade the quality standard of biomass. It is, however, highlighted that conducting torrefaction early in the production chain can significantly improve the quality of biofuel and biochemicals (Medic *et al*. 2012; Abdullah *et al*. 2017).

Sadaka and Sunita (2009) studied the improvement of physical and thermochemicalcharacteristics of wheat straw, rice straw, and cotton gin waste at 260 °C for 0, 15, 30, 45 and 60 min using a batch torrefaction. They found that during the torrefaction of biomass at 60 min the moisture content was profoundlydecreased. Consequently, the heating value was determined to improve. Jafar and Ahmad (2011) investigated the potential of torrefaction to enhance the properties of palm kernel shell as a solid fuel. They experimented with atemperature of 240, 260 and 280 °C and residence time of 30, 60, and 90 min. They observed that the torrefaction affect the mass and energy yield of the palm kernel shell (PKS) which was highly associated with the influence of the torrefaction temperature more than the residence time. The Malaysian agricultural wastes such as empty fruit bunch, mesocarp fiber, and palm kernel shell were torrefied and found that torrefaction led to the higher calorific value and carbon content increment (Uemura *et al.* 2011; Abdullah *et al*. 2016). A Huge amount of EFB is discarded in palm oil mill factories which became problematic to environmental sanitation. Moreso, it is acknowledged that this waste contains a significant amount of heating value of about 16 $MJkg^{-1}$. In this research, the influence of torrefaction temperature on the torrefaction of EFB will be investigated. Torrefaction experiment was conducted on EFB at three different temperature of 200, 250 and 300 °C and, at a constant heating rate and residence time of 10 $^{o}Cmin^{-1}$ and 30 min, respectively.

MATERIALS AND METHODS

Torrefaction Experiment

Torrefaction experiment of the biomass samples was conducted three times separately using a stainless steel reactor of150 mmlength and 70 mm internal diameter. The reactor was fed with about 180 g raw obtained from oil palm mill EFB, it was place inside the electric furnace. The reactor was heated by the heat released into anelectricfurnace. The reactor temperature was monitored by inserting K-type thermocouples inside the reactor. For each experiment run, nitrogen gas was used as areaction gas at a rate of 2 liters per minute. The temperaturewas varied from 200, 250 and 300 °C, at a heating rate and reaction time of 10 $^{o}Cmin^{-1}$ and 30 min, respectively. The proximate and elemental analysis processes is reported in the previous work of Abdullah *et al*. 2017.

The torrefaction products liquid and non-condensable gases were passed through acooling system which was regulated at 5 °C. Liquid produced was condensed and collected in the flasks numbered 1 and 2, whereby the non-condensable gasses exit the system through thegas outlet. Figure 1 illustrates the schematic experimental setup. Before and after each run, the reactor weight was measured, and the quantity of solid product left was calculated from the difference. The liquid yield was calculated by subtracting initial from final weight of flasks, condensers, L-tube, long tube and pipes, while non-condensable gas was calculated from the difference of solid and liquid from 100%. Finally, the solid and energy yields of torrefaction were computed using the following formula as reported by (Uemura *et al*. 2011).

$$\text{Solid yield (\%)} = \frac{\boldsymbol{Productweightaftertorrefaction}}{\boldsymbol{Rawsampleweightbeforetorrefaction}} \times \mathbf{100} \quad (1)$$

$$\text{Energy yield (\%)} = \frac{\boldsymbol{HHVoftheProduct}}{\boldsymbol{HHVoftherawsample}} \times \boldsymbol{solidyield} (2)$$

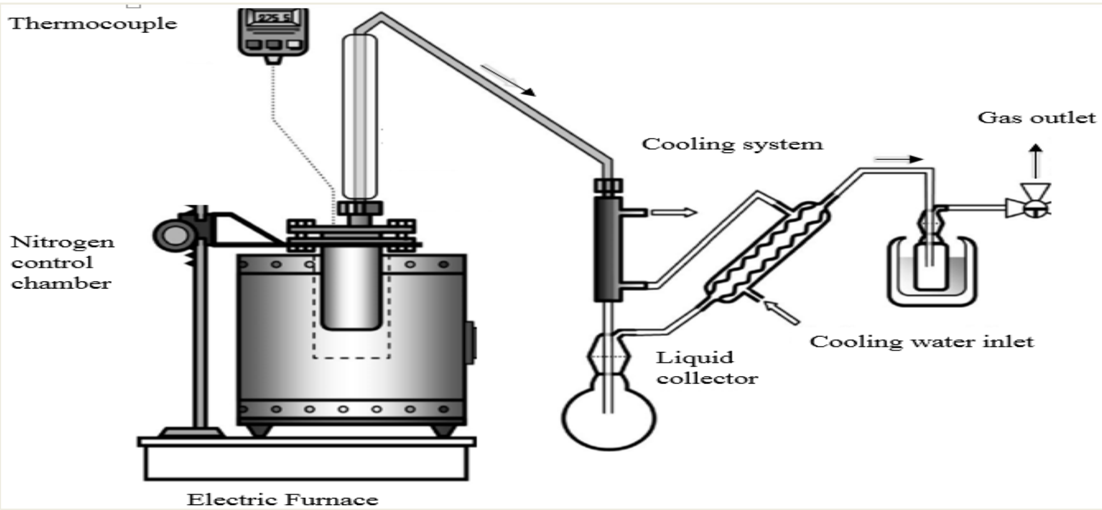

Figure 1. A schematic of the experimental system(Safana A.A et al. 2018).

RESULT AND DISCUSSION

Figure 2 shows the distribution of oil palm biomass waste. Palm shell and palm fiber were utilized as fuel to power the steam boilers, whereas empty fruit bunch is used for mulching in the plantation area (Idris *et al*. 2012).However, the proportions of agricultural residues generated from oil palm include mesocarp fiber 13.5%, palm kernel shell 5.5% and empty fruit bunch 22%(Sulaiman *et al.* 2010, Kong *et al*. 2014). The oil extraction rate is just around 10% of the palm oil production with the larger part 90% remaining as biomass.For instance, in 1 kg of palm oil about 4 kg of dry biomass is generated (Sulaiman *et al*. 2010; Kong *et al*. 2014).One of the significant advantages of oil palm wastes is that the palm oil mill is independent in energy, utilizing mesocarp fibre (MF), EFB, and shell as fuel to generate steam in wastefuel boilers for handling, and power-generation with steam turbines (Abdullah and Sulaimam 2013).

Figure 2. Product and waste distribution from oil palm tree. Source (JFE project, 2016: http://jfe-project.blogspot.my/2010/04/utilization-biomass-oil-palm.html).

Torrefaction Products Yields

The influence of temperature on the torrefaction products yield is shown in Table 1. The solid, liquid and gas yieldwas in the range of 70-85 wt%, 5-12 wt%, and 10-18 wt%, respectively. It can be seen from Table 1 that increased temperature decreases solid yield. However, the differences in the solidyields between the temperatures are relatively modest. The decrease could be as a result of an increase in devolatisation at higher temperatures. Nevertheless, higher temperatures favour high yield of liquid and gas as shown in Table 1. However, the quantity of liquid produced is small compared to solid product. This implies that torrefaction of oil palm EFB produces non-condensable gases. It can, therefore, be described as a secondary drying method where a high percentage of moisture is removed.

Table 1. Torrefaction products yield

Products (wt%)	200 ^{o}C	250 ^{o}C	300 ^{o}C
Solid	85	80	70
Liquid	5.0	8.0	12
Gas	10	12	18

Physicochemical Properties of the Solid Products

The results obtained from the proximate analysis of raw (dried) and torrefied biomass are given in Table 2. The ash content and volatile matter content of the raw biomass decreased after torrefaction, whereas the fixed carbon increased in the torrefied biomass. The volatile matter content in the dried EFBwas found to be 82.40 wt% which reduced to 74.32 wt% at 300 ^{o}C. The volatile matter content is regarded as a factor in identifying the ignition status of thesample, the higher the percentage of volatile matter the simple is the ignition. Ash content is an impurity that cannot be burn (Valkovic 1985).The properties of the torrefied biomass rely enormously on the torrefaction temperature (Chen and Kuo 2011).The elemental analysis showed that carbon content increased while oxygen decreased. The maximum carbon and minimum oxygen contents were recorded at 300 ^{o}C with 46.97 and 45.59 wt%, respectively. Uemura *et al*. 2011 also reported similar finding that the increase in torrefaction temperature resulted in higher calorific value, lower moisture, volatile matter and ash contents, and increased fixed carbon content.

Table 2. Physiochemical properties of torrefiedproducts

Properties (wt%)	Temperature ^{o}C			
	105 (dried)	200	250	300
Moisture	7.30	6.67	5.34	3.79
Ash content	7.51	7.41	6.98	7.79
Volatile matter	82.40	80.11	77.96	74.32
Fixed carbon[b]	10.09	13.23	15.06	17.89
Carbon	42.80	44.09	46.61	46.97
Hydrogen	6.20	6.02	6.08	6.71
Nitrogen	0.47	0.76	0.78	0.62
Sulfur	0.09	0.12	0.15	0.11
Oxygen[b]	50.44	48.71	46.38	45.59

[b]Obtained by calculating the difference

The highest fixed carbon of 17.89 wt% was obtained at 300 ^{o}C. Fixed carbon serves as a primary source of heat during burning. An increase and decrease were observed in the ash content and fixed carbon, and the moisture and volatile matter, respectively (Jaafar and Ahmad 2011), which agrees with the finding in this work.It was discovered that the heating value of biomass hasincreased from 16.90 to 20.96 MJkg^{-1}after torrefaction. This increase was due to the decrease in oxygen and hydrogen contents and raised in carbon content, respectively as shown in Table 2. However,the effect of torrefaction was observed higher at 300 ^{o}C, may be due to high moisture and high volatile matter content reduction in the raw sample and consequently increased the calorific value. The calorific value of raw and torrefied biomassis presented in Figure 3. The decomposition reactions that occured during torrefaction making the biomass wholly dried and increases the calorific value, and also provide a biomass which is hydrophobic (Kiel 2005).

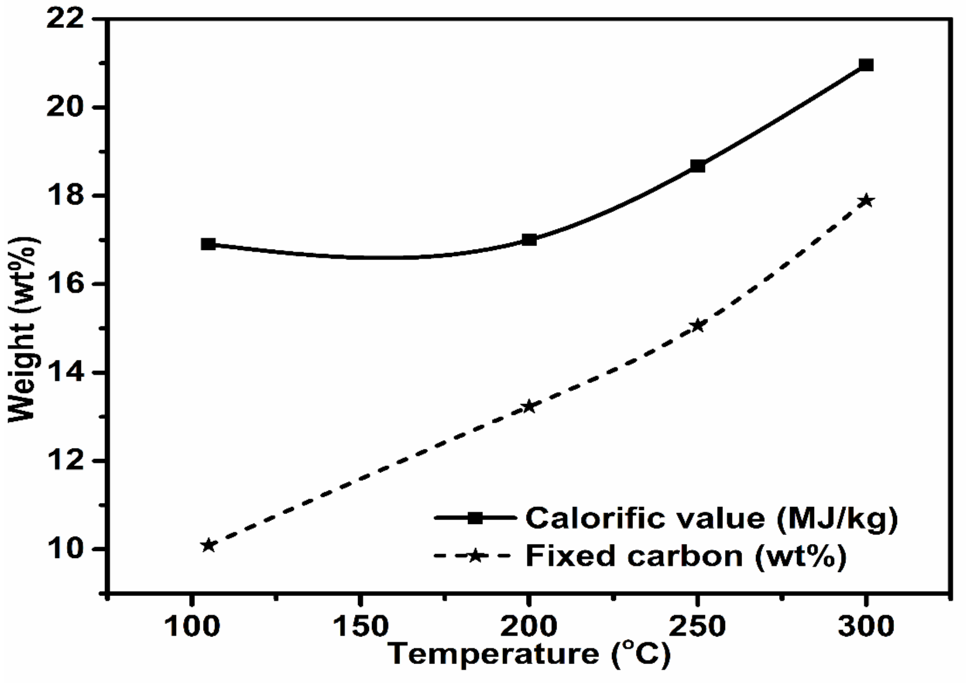

Figure 3: Increase in calorific value and fixed carbon versus temperature

Energy Yields

The energy yields are dependent on solidyields and calorific value of the raw and torrefied samples. Figure 4 present theenergy yields at different temperatures, it can be noticed from Figure 4 that the energy yield for torrefied EFB at 200, 250 and 300 ^{o}C were 91, 94 and 99 %, respectively. This demonstrates that the energy yield is increasing with temperature increase. It may be due to the increase in calorific value at higher temperatures. As shown previously in Table 1, EFB comprises of high moisture content and volatile matter. These constituents were released during the torrefaction, and consequently, the calorific value is improved. The high-energy yield obtained at 300 ^{o}C is connected with the difference in heating value between raw and torrefied EFB (Figure4), and the amount of solid yield. The energy yield for torrefied EFB at 250 ^{o}C for 30 min was reported to be 73% (Uemura *et al.* 2011).

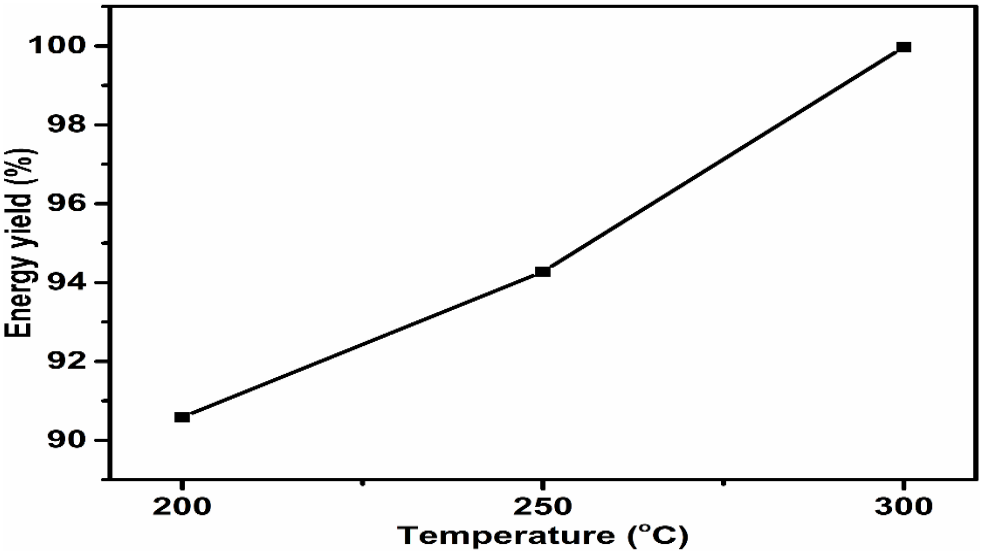

Figure 4: Energy yields at different temperatures

CONCLUSION

In this study, the effect of torrefaction temperature on the torrefaction products yield, energy yield and the physiochemical properties of solid products were investigated. It was found that the torrefaction temperature significantly influenced the products yield and the properties of the torrefied biomass. However, torrefaction improved the calorific value, fixed carbon, carbon content by reducing moisture, volatile matter and hydrogen content of the biomass. Therefore, torrefaction of biomass within a temperature range of 200-300 ^{o}C could be described as advanced drying method to improve the quality of biomass. Other parameters such as heating rate, retention time, nitrogen flow rate and nature of biomass could also influence the quality and quantity of the torrefaction products. It is therefore recommended that these parameters should also be investigated.

Acknowledgement

The authors wish to express their gratitude to the TETFUND for financing this research.

REFERENCES

Abdullah, N., Safana, A. A., Sulaiman, F., Abdullahi, I. I. (2017). A Comparative Analysis of Physical and Chemical Properties of Biochars and Bio-Oils Obtained from Pyrolytic Process of Mesocarp Fibre and Empty Fruit Bunch. *Solid State Phenomena* 268**,** 387-392.

Abdullah, N., Sulaiman, F.(2013). Chapter 3: The Oil Palm Wastes in Malaysia. *Biomass Now- Sustainable Growth and Use* (Matovic, M D ed.). DOI: 10.5772/55302.http://www.intechopen.com /books / biomass-now-sustainable-growgth-and-use / the-oil-palm-wastes-in-malaysia.

Abdullah, N., Safana, A. A., Sulaiman, F., Abdullahi, I. I. (2016). Potential application of oil palm wastes for coal replacement. *AIP Conference Proceedings 1774,* 1774**,** 020004. DOI: 10.1063/1.4965052.

Abdullah, N., Safana, A. A., Sulaiman, F.(2017). Pyrolysis of torrefied oil palm wastes forbetter biochar. *Malaysian Journal of Fundamental and Applied Sciences* 13**:** 124-128.

Chen, W-H., Hsu, H-C., Lu, K-M., Lee, W-J., Lin, T-C. (2011). Thermal pretreatment of wood (Lauan) block by torrefaction and its influence on the properties of the biomass. *Energy* 36**:** 3012-3021.

Chen, W-H., Kuo, P-C. (2011). Torrefaction and co-torrefaction characterization of hemicellulose, cellulose and lignin as well as torrefaction of some basic constituents in biomass. *Energy* 36**:** 803-811.

Idris, S. S., Rahman, N. A., Ismail, K.(2012). Combustion characteristics of Malaysian oil palm biomass, sub-bituminous coal and their respective blends via thermogravimetric analysis (TGA). *Bioresource technology* 123**:**581-591.

Jaafar, A., Ahmad, M. (2011). Torrefaction of Malaysian palm kernel shell into value-added solid fuels. *World Acad. Sci. Eng. Technol* 5**:** 554-557.

Kiel, J. H.A., Patrick .C.A. B. (2005). Torrefaction For Biomass Upgrading. Published at 14th European Biomass Conference and Exhibition, Paris, France, 17-21 October 2005. Available at http:// www.ecn.nl/biomass.

Kong, S-H., Loh, S-K., Bachmann, R. T., Rahim, S. A., Salimon, J. (2014). Biochar from oil palm biomass: A review of its potential and challenges. *Renewable and Sustainable Energy Reviews,* 39**:** 729-739.

Medic, D., Darr, M., Shah, A., Potter, B., Zimmerman, J. (2012). Effects of torrefaction process parameters on biomass feedstock upgrading. *Fuel* 91**:** 147-154.

Sadaka, S., Negi, S. (2009). Improvements of biomass physical and thermochemical characteristics via torrefaction process. *Environmental Progress Sustainable Energy* 28**:** 427-434.

Sulaiman, F., Abdullah, N., Gerhauser, H., Shariff, A. (2010). A perspective of oil palm and its wastes. *J Phy Sci.* 21**:** 67-77.

Uemura, Y., Omar, W. N., Tsutsui, T., Yusup, S. B. (2011). Torrefaction of oil palm wastes. *Fuel* 90**:** 2585-2591.

Valkovic, V. (1985). Trace elements in coal and other mineral resources in Turkey. Japan and China workshop on mining 1987.