Australian Journal of Basic and Applied Sciences, 10(17) Special 2016, Pages: 114-121

AUSTRALIAN JOURNAL OF BASIC AND APPLIED SCIENCES

ISSN:1991-8178 EISSN: 2309-8414
Journal home page: www.ajbasweb.com

Improvement Empty Fruit Bunch Properties through Torrefaction

[1]Thuraiya Thaim and [2]Ruwaida Abdul Rasid

[1,2]Universiti Malaysia Pahang, Faculty of Chemical Engineering and Natural Resources, 26300, Gambang, Pahang, Malaysia.

Address For Correspondence:
Ruwaida Abdul Rasid2 Universiti Malaysia Pahang, Faculty of Chemical Engineering and Natural Resources, 26300, Gambang, Pahang, Malaysia. Tel: 0133669874. Fax: 09-5492889, e-mail: ruwaida@ump.edu.my

ARTICLE INFO

Article history:
Received 19 August 2016
Accepted 10 December 2016
Published 31 December 2016

Keywords:
Torrefaction, Empty Fruit Bunch (EFB), Solid yield, Energy yield, Energy production

ABSTRACT

The world is currently facing challenges to reduce dependence on fossil fuels and to achieve a sustainable and renewable energy supply. With environmental issues associated with conventional fossil-based fuels such as the release of the greenhouse gases, more researchers are turning to find alternatives, and this leads to applying biomass waste as one of the renewable energy source. However, there are setbacks in utilizing the biomass waste directly, such as it having high moisture content, and low energy density. This can be overcome through torrefaction, which is a thermal pre-treatment technique at temperatures ranging from 200 – 300ºC. The aim of this work is to improve the biomass waste properties through torrefaction. In this study, the oil palm Empty Fruit Bunch (EFB) was examined, and its properties were characterized based on severe torrefaction temperatures (280, 300 and 320ºC) and at various residence time (30, 60 and 90 minutes). The results revealed that the torrefaction temperature have significant effect the mass yield and high heating value of EFB. At temperature 320ºC and 30 minutes' residence time, the mass yield was 57.97% and the high heating value (HHV) was 22.10 MJ/kg. This is an improvement as the HHV of the torrefied EFB was 27.31% higher than that of the raw EFB. This can be observed at temperature 280ºC, when the residence time was prolonged, there was insignificant increase in mass yield. Increasing the residence time results in only a slight increment for all of the severe torrefaction temperature. This suggests that the 30 minutes' residence time is sufficient, and prolonged exposure to the torrefaction temperature will not affect the physical properties of the torrefied biomass. This study has highlighted the potential of EFB as one of the feedstock for energy production process through thermal treatment.

INTRODUCTION

The energy consumption in Malaysia is mainly based on fossil fuels such as natural gas, coal and petroleum. It is estimated that Malaysia will be able to produce oil and gas for the next 18 and 35 years, respectively (Nabli, 2011). The alternative fuels such as renewable energy resources are the best substitute for fossil fuels. Renewable energy can be divided into biomass, solar, tidal, wind and hydro power. Among these renewable energy sources, biomass is one of the most potential renewable energy in Malaysia (Petinrin & Shabaan, 2015).

Biomass is considered as an important renewable energy. They can be from crops, grasses, agricultural crops and wastes, wood residues, animal wastes and municipal wastes. Malaysia as one of the main oil palm tree producer (Sumathi *et al*., 2008) generating high amount of agricultural wastes, hence, the availability of large quantities of oil palms biomass in Malaysia is promising for future generation of renewable energy. The types of biomass produced by the oil palm industry includes empty fruit bunches (EFB), mesocarp fiber, palm kernel shells (PKS), fronds and trunks. There are many ways biomass can be changed into energy, through of thermochemical conversions, biochemical conversions, and extraction of oil from oil bearing seeds. Among

To Cite This Article: Thuraiya Thaim and Ruwaida Abdul Rasid., Improvement Empty Fruit Bunch Properties through Torrefaction. ***Aust. J. Basic & Appl. Sci.,*** *10(17): 114-121, 2016*

these methods, thermochemical conversions process through gasification is the best technique because it may reduce toxic emissions, improve thermal efficiency and has the ability generate hydrogen and other high-value fuels (Chen *et al*., 2011). However, prior to the application, the biomass needs to be pre-treated to improve its properties, and this may be done through torrefaction.

Torrefaction is a biomass thermal pre-treatment technique at temperatures ranging from 200 – 300ºC (Chen *et al*., 2011, Rousset *et al*., 2012, Duncan *et al*., 2013). Torrefaction is important to improve the biomass quality and reduce some of its problem such as low heating value and energy density, high moisture content, low combustion efficiency and high grinding energy requirements. Torrefaction increases the energy density of biomass by reducing its oxygen content leading to a torrefied biomass product with heating values nearing those of coal (van der Stelt *et al*., 2011, Medic *et al*., 2012, Sarvaramini *et al*., 2013). During the torrefaction process, biomass loses more oxygen and hydrogen compared to carbon. At the end of the torrefaction process, the product form from this process has better grindability, high hydrophobicity, and a higher calorific value compared to the original raw material (Arias *et al*., 2008, Oliveira and Rousset, 2009, Almeida *et al*. 2010).

Biomass has three (3) main sugar-based polymeric structures which are hemicellulose, cellulose, and lignin. Depending on the torrefaction temperature and biomass residence time, hemicellulose, cellulose and lignin content of biomass are partly decomposed. The decomposition of biomass during torrefaction leads to the production of some condensable and non-condensable gases also solid products. According to Mohammad *et al*., (2005) the chemical composition of EFB for hemicellulose, cellulose and lignin were 35.3 wt%, 38.3%, and 22.1 wt% respectively.

Bridgeman *et al*., (2008) focused on the torrefaction of reed canary grass, wheat straw and willow with temperature 230, 250, 270 and 290ºC with 30 minutes residence time. It was reported that carbon content increased while hydrogen and oxygen content decreased with temperature increased. Pimchuai *et al*., (2010) torrefied agriculture residues (sawdust, peanut husks, bagasse and water hyacinth) at temperature 250, 270 and 300ºC with 1-2 hours residence time. They found that the increase of temperature will decrease the percentage of mas and energy yield. Besides, calorific value increased, moisture content and volatile matter decreased, with increased temperature and residence time. They also concluded that the temperature has more effects on torrefaction process than residence time. Medic *et al*., (2012) focused on corn stover biomass with temperature 200, 250 and 300ºC and residence time 10, 20 and 30 minutes. They concluded that the temperature had a stronger impact on the increase in the energy density of the torrefied biomass compared with residence time. Chen *et al*., (2011) investigated the effect on the torrefaction temperature (230, 250, 270 and 290ºC) and residence time (20 and 30 minutes) on the solid product. They found that the changes in weight loss were small when the residence time was more than 30 minute. Hence, it was thought that a residence time of more than 30 minute would not have significant effect on torrefaction. Uemura *et al*. (2013) studied the reaction time and temperature with different oxygen concentration of oil palm wastes. Their findings indicated that increasing temperature has lowering solid yield. The difference in solid yield between the atmospheric conditions may be due to oxidation of biomass to form a gaseous product in an oxidizing atmosphere (Uemura *et al*., 2013).

Previous researchers have focused on torrefaction of wood residues and less attention has been paid to the torrefaction Malaysia's agricultural biomass specifically oil palm wastes such as EFB. EFB is the utmost contributors of oil palm biomass with around 15.8 MnT production/year (Sumathi *et al*., 2008). EFB can be turned out to be useful feedstock to generate energy through torrefaction process. Hence, the aim of the present study is to investigate the torrefaction EFB under atmospheric conditions at the severe torrefaction temperatures (280, 300 and 320ºC) and different residence time (30, 60 and 90 minutes).

Research Methodology:

Materials:

Empty Fruit Bunch (EFB) was obtained from Felda Lepar Hilir, Gambang, Kuantan, Pahang. All of the samples were oven dried at 105ºC for 24 hours to provide a basis of the tested materials and to determine the oven-dry mass before torrefaction. After drying, the raw material was grounded and sieved into 250 – 500 µm. Then, the prepared raw sample was transferred into labelled air-tight container contained with silica gel in order to control moisture content and the sample stored until the experiments were carried out.

Methodology:

Torrefaction biomass samples were carried out using a vertical tubular stainless steel reactor, with a diameter of ½ inch. The entire set-up is illustrated in Figure 1.

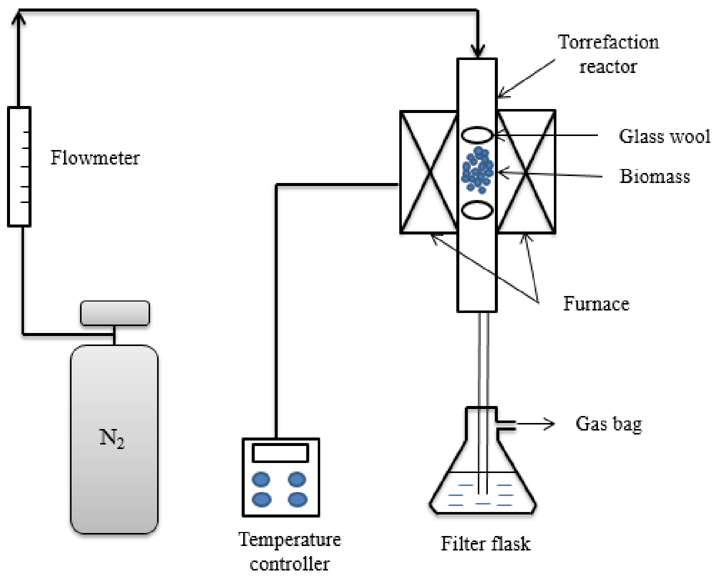

Fig. 1: Experimental apparatus used in this study.

A prescribed amount of biomass wastes (3.0 g) was weighed and placed in the reactor. The nitrogen (N_2) gas is supplied from cylinder tank at 30 ml/min. The sample is heated up to the desired temperatures (280, 300 and 320°C) at a heating rate of 10°C/min and once the temperature is achieved the reaction is allowed to take place for 30, 60 and 90 minutes. The biomass is cooled down to room temperature before the torrefied biomass was retrieved and weighted. The torrefaction experiment is replicated at least three (3) times to ensure consistency.

Measurements:

The mass and the calorific value were measured before and after torrefaction for every sample. Higher heating value (HHV) was calculated according to the Dulong formula (Yuan *et al.*, 2009), Eqn. 1 based on the data of elemental analysis:

$$\mathrm{HHV}\left(\frac{\mathrm{MJ}}{\mathrm{kg}}\right) = 0.3383Z_C + 1.422(Z_H - \frac{Z_O}{8}) \qquad \text{(Eqn.1)}$$

where Z_C, Z_H, and Z_O are the weight percentage of C, H, and O respectively from CHNS analysis. The mass yield was calculated according to the equations 2: (Uemura *et al.*, 2011):

$$y_M = \frac{\text{Mass of solid after torrection}}{\text{Mass of EFB used}} \times 100\% \qquad \text{(Eqn.2)}$$

where y_M is the mass yield (%).

RESULTS AND DISCUSSION

Physical Properties of Torrefied Sample:

Solid product is the major product for torrefaction. The color of torrefied biomass depends on torrefaction parameters (temperature, residence time and types of biomass). Figure 2 presents the pictures of raw EFB and torrefied EFB at different temperatures at 30 minutes residence time. It shows that the color of the biomass changes from light brown to black when temperature was increased. At 280°C, the color of torrefied EFB is slightly brownish in color, which indicates that at 280°C, the biomass was not completely burn. On the other hand, at 320°C, the color of torrefied biomass was completely black. Uemura *et al.*, (2011) reported similar appearance of the solid yield. The color changes may be due to drying process in torrefaction, while removing of surface and bound water from the raw biomass and resulted decrease in moisture content (Tumulu *et al.*, 2011).

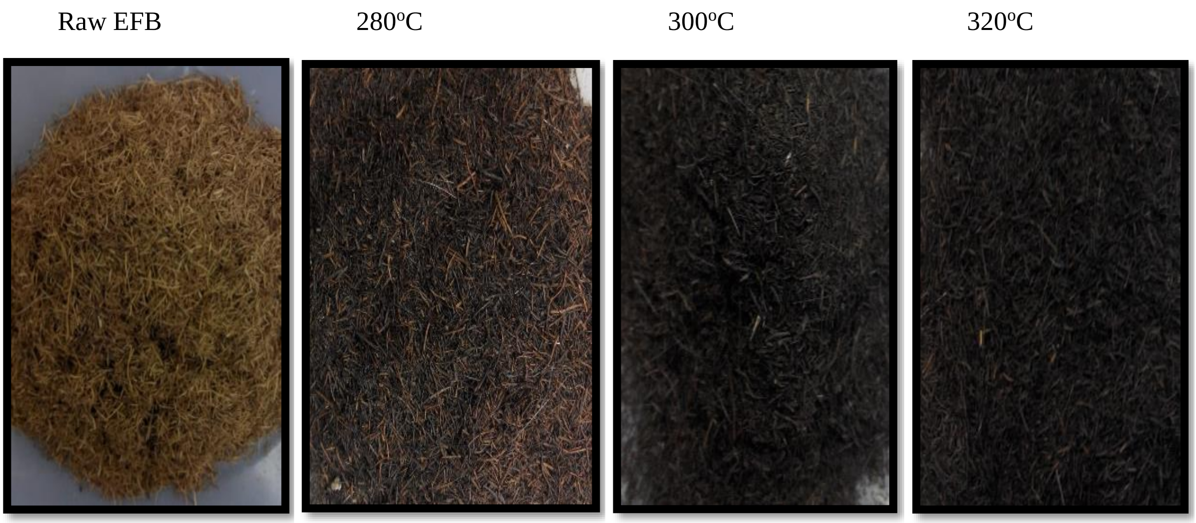

Fig. 2: Appearance of raw and torrefied sample.

Ultimate Analysis:

The ultimate analysis of biomass samples are presented in Table 1. From the table, it can be observed that with increasing temperature, the carbon content is also increased. Based on the three temperatures investigated (280, 300 and 320ºC), the highest carbon content was 62.10% at 320ºC and 90 minutes of residence time. Based on this data, carbon content showed increment of 39.48% from raw EFB. An increase in temperature from 280 to 320ºC, slightly increase the carbon content from 51.90% to 62.10%. Meanwhile, both hydrogen and oxygen content was decreased with increasing temperature. In comparison to raw EFB, both hydrogen and oxygen content shows decrement at 320ºC; 55.53% and 51.76%, respectively. This might due to the loss of water and carbon dioxide during torrefaction process (Prins *et al*., 2006).

Table 1: Ultimate analysis for raw and torrefied EFB.

Temperature (ºC)	Residence time (min)	C (%)	H (%)	N (%)	S (%)	O (%)
Raw EFB	-	44.52	7.41	1.33	0.41	46.33
280	30	54.97	6.16	2.41	0.18	36.28
	60	55.12	6.04	4.18	0.18	34.48
	90	51.90	6.18	2.10	0.21	39.61
300	30	58.93	5.29	2.45	0.17	33.16
	60	56.85	5.85	2.49	0.16	34.66
	90	60.36	5.45	2.32	0.17	31.69
320	30	59.21	5.58	2.05	0.13	33.02
	60	58.72	5.21	2.15	0.15	33.78
	90	62.10	4.76	2.45	0.16	30.53

Proximate Analysis:

The proximate analysis (PA) of raw and torrefied EFB at 280, 300 and 320ºC is shown in Figure 3. The volatile matter of EFB emits a decreasing trend as the temperature is increased where it decreases from raw EFB 69 wt% reduces to 14 wt%. This can be observed whereby the VM of raw EFB is increasing. This changes may be translated to 45-79 wt% decreased with respect to the raw sample. Chen *et al*., (2014) reported the similar trend. VM and FC are two important parameters of solid fuels, whereby high VM means that the fuel is more reactive but has less calorific value (Chen *et al*., 2014). On the other hand, FC is increased, when increasing temperature. Based on three temperatures that investigated (280, 300 and 320ºC), the highest FC was 19.46 wt% at 320ºC. Based on this data, FC showed increment about 69.71% from raw EFB. This observation is also consistent with other researchers (Jaafar & Ahmad, 2011, Pimchuai, *et al*., 2010). The decreasing VM and increasing FC might be due to decomposition and devolatilization reaction that takes place. Higher FC on the other hand means that the fuel is less reactive but has high calorific value (Chen *et al*., 2014).

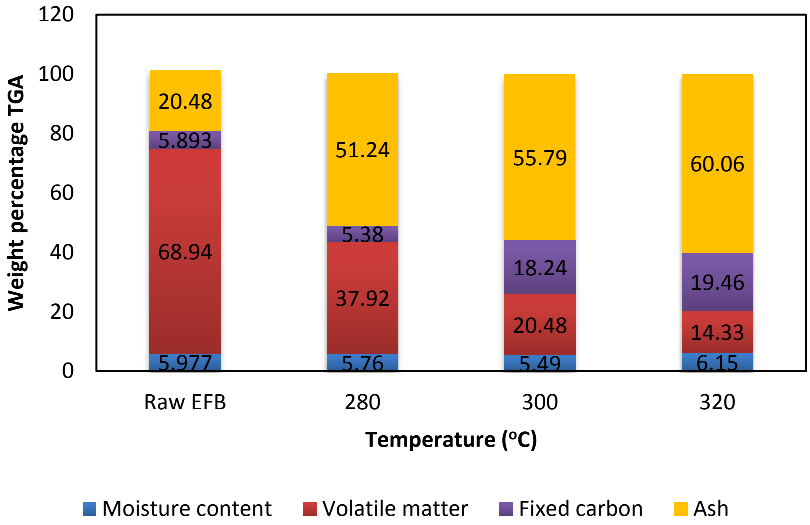

Fig. 3: Proximate analysis for raw and torrefied EFB.

Mass Yield:

Mass yield can be defined as the percentage of biomass solid retained after torrefaction process (Eqn. 2). Figure 4 presents the effect of temperature on solid yield of torrefied EFB. It is observed that the mass yield gradually decreased with increasing temperature. The highest mass yield was 58.39% for the torrefaction at 280°C. Meanwhile, the lowest mass yield was 57.87% at temperature 300°C. Besides, based on Figure 4, it show that mass yield has small increment when achieved 320°C after experiment was repeated three times. So, 300°C is the optimum temperature that can be achieved in terms of mass yield compared with 320°C this relates with result moisture content show slightly increasing at 320°C.The decreased in mass yield may be due to enhanced degradation of lignocellulosic compound of biomass at higher temperature. Mohammad *et al.*, (2005) claims that chemical composition of EFB for hemicellulose, cellulose and lignin were 35.3 wt%, 38.3% and 22.1 wt% respectively. Specifically, hemicellulose is the most reactive component of lignocellulosic biomass, decomposes at temperatures 150 – 350°C, while cellulose decomposes at temperatures 275 – 350°C. Besides, lignin decomposition occurs between 250 – 500°C (Arias *et al.*, 2008). The highest mass yield occurs at 280°C, which indicates that the decomposition of reactive component in the range of torrefaction temperature.

With regard to the residence time for the torrefaction process at 280°C, it is observed that as the residence time was prolonged, there was an insignificant change in mass yield. For residence time of 60 and 90 minutes, there is only slight change at all three (3) temperature as small variation is observed. This implies that longer residence time may not be as important to improve the fuel physicochemical properties compared with temperatures.

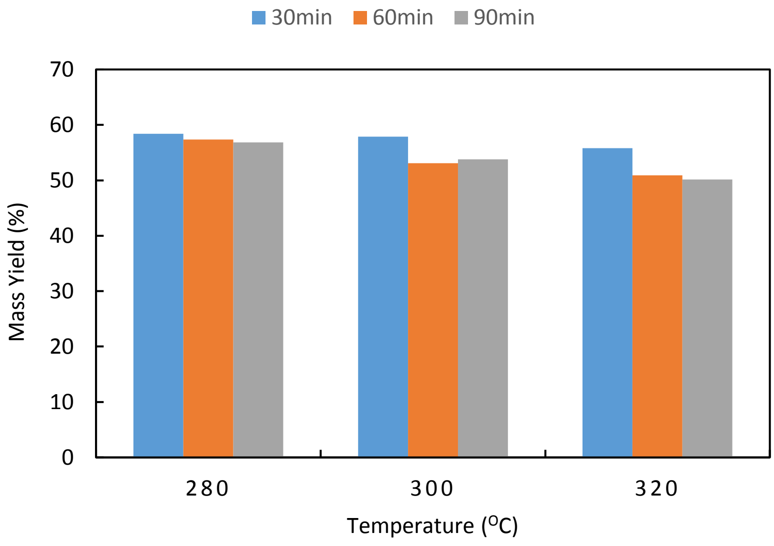

Fig. 4: Mass yield percentage of EFB at different temperature.

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Calorific Value:

Figure 5 presents the relationships between calorific value against temperature of EFB. The calorific value increased with increasing temperature. At temperature 320ºC and 30 minutes residence time, the HHV was 22.10 MJ/kg. This is an improvement as the HHV of the torrefied EFB was 27.31% higher than that of the raw EFB. The results obtained are consistent with other researchers which reported that calorific value increased with temperature (Uemura *et al*., 2013, Pimchuai *et al*., 2010). The trend of calorific value can be related to ultimate analysis where an increase in the C:C concentration leads to increase of HHV.

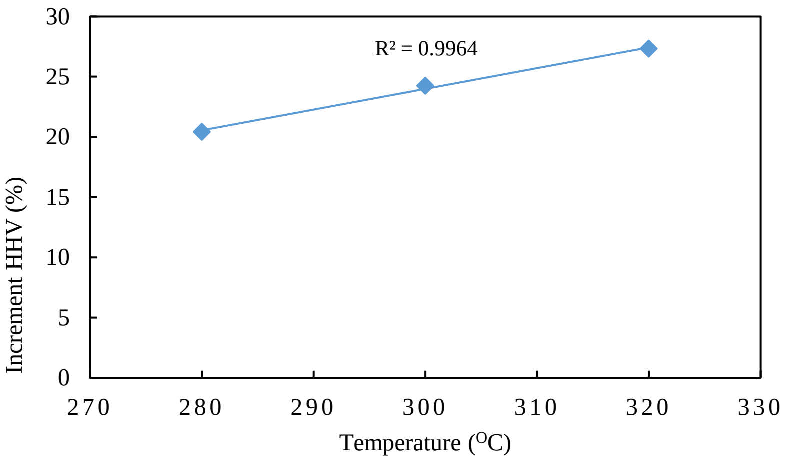
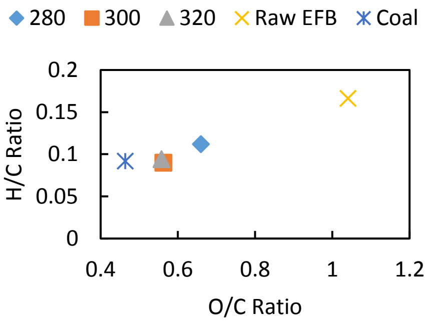


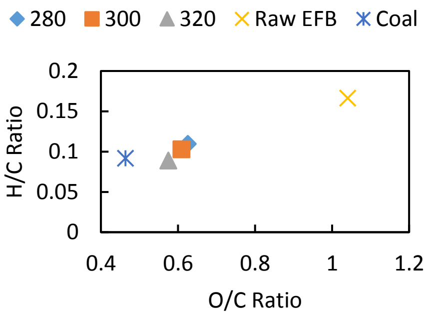
Fig. 5: Increment HHV of EFB at different temperature.

Comparison Efb With Coal:

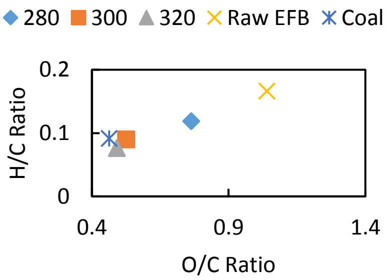
In order to compare EFB results with coal, the graph O/C ratio versus H/C ratio that called as Van Krevelen diagram was plotted as shown in Figure 6. As temperature and residence time increase, the O/C and H/C ratio are closer to coal. This is due to drying and devolatilization process in torrefaction that remove of surface water and carbon dioxide (Prins *et al*., 2006). It show clearly that torrefied EFB has potential to use as a feedstock due to lower in O/C ratio and H/C ratio especially at temperature 300 and 320ºC.



a) 30 minutes



b) 60 minutes



c) 90 minutes

Fig. 6: Van Krevelen diagram. a) 30 minutes b) 60 minutes c) 90 minutes

Conclusion:

Torrefaction of oil palm EFB was carried out in the inert atmosphere in order to investigate the effects of temperature and residence time on the characteristics of solid products. The color of the biomass changes from light brown to black when temperature was increased. The mass yield decreased with increasing temperature and residence time. The longer residence time may not be as important to improve the fuel physicochemical properties compared with temperatures. The calorific value increased with increasing temperature. Lastly, the Van Krevelen diagram show clearly that torrefied EFB has potential to use as a feedstock due to lower in O/C ratio and H/C ratio especially at temperature 300 and 320ºC Therefore, it proved that EFB can be turned out to be useful feedstock to generate energy through torrefaction process.

ACKNOWLEDGMENT

This project was supported by the Ministry of Higher Education Malaysia (RDU140134) and Universiti Malaysia Pahang (RDU150366). The authors also thank the Faculty of Chemical Engineering and Natural Resources, Universiti Malaysia Pahang for providing the lab space to conduct the trials.

REFERENCES

Almeida, G., J.O. Brito and P. Perre, 2010. “Alterations in energy properties of eucalyptus wood and bark subjected to torrefaction: The potential of mass loss as a synthetic indicator,” Bioresource Technol., 101(24): 9778-9784.

Arias, B., C.P evida, J. Fermoso, M.G. Plaza, F. Rubiera and J.J. Pis, 2008. “Influence of torrefaction on the grindability and reactivity of woody biomass,” Fuel Process Technol., 89(2): 169-75.

Bridgeman, T., J. Jones, J. Shield and P. Williams, 2008. Torrefaction of reed canary grass, wheat straw and willow to enhance solid fuel qualities and combustion properties. Fuel, 87: 844-56.

Chen, W.H., H.C. Hsu, K.M. Lu, W.J. Lee, T.C. Lin, 2011. Thermal pretreatment of wood (Lauan) block by torrefaction and its influence on the properties of the biomass. Energy, 36: 3012-21.

Chen, Q., J.S. Zhou, B.J. Liu, Q.F. Mei, 2011. Influence of torrefaction pretreatment on technology. Energy Science & Technology, 56(14): 1449-1456.

Chen, W., K. Lu, W. Lee, S. Liu and T. Lin, 2014. Non-oxidative and oxidative torrefaction characterization and SEM observations of fibrous and ligneous biomass. Applid Energy, pp: 104-113.

Duncan, A., A. Pollard, H. Fellouh, 2013. Torrefied, spherical biomass pellets through the use of experimental design. Appl Energy, 101: 237-243.

Jaafar, A. and A. Ahmad, 2011. Torrefaction of Malaysia Palm Kernel Shell into Value-Added Solid Fuels. International Journal of Chemical Nuclear, Materials and Metallurgial Engineering, 5(12).

Medic, D., M. Darr, A. Shah, B. Potter, J. Zimmerman, 2012. Effects of torrefaction process parameters on biomass feedstock upgrading. Fuel., 91: 147-54.

Mohammed, M.A.-R.-Y., 2005. Hydrogen rich gas from oil palm biomass as a potential source f renewable energy in Malaysia. Renewable Sustainable Energy Rev., 15: 1258-1270.

Nabli, M.K., 2011. The Great Recession and Developing Countries: Economic Impact and Growth.

Oliveira, T. and P.L.A. Rousset, 2009. “Effects of torrefaction on energy properties of *Eucalyptus grandis* wood,” *Cerne* 15(4): 446-452.

Petinrin, J. and M. Shabaan, 2015. Renewable enegy for continuous energy sustainability in Malaysia. Renewable and Sustainable Energy Reviews, 50: 967-81.

Pimchuai, A., A. Dutta and P. Basu, 2010. Torrefaction of agriculture residue to enhance combustible properties. Energy and Fuels, 24: 4638-45.

Prins, M., K. Ptasinski and F. Janssen, 2006. Torrefaction of wood Part 2. Analysis of Products. Journal of Analytical and Applied Pyrolysis, 77: 35-40.

Rousset, P., L. Macedo, J.M. Commandre, A. Moreira, 2012. Biomass torrefaction under different oxygen concentrations and its effect on the composition of the solid by-product. J Anal Appl Pyrol, 96: 8-91.

Sarvaramini, A., O. Gravel, F. Larachi, 2013. Torrefaction of ionic-liquid impregnated lignocellulosic biomass and its comparison to dry torrefaction. Fuel., 103: 814-26.

Uemura, Y., W.N. Omar, N.A. Othman, S. Yusup, T. Tsutsui, 2011. Effect of atmosphere on torrefaction of oil palm wastes. Bioenergy Technology.

Uemura, Y., W. Omar, N. Othman, S. Yusup and T. Tsutsui, 2013. Torrefaction of oil palm EFB in the presence of oxygen. Fuel, 103: 156-60.

van der Stelt MJC, H. Gerhauser, J.H.A. Kiel, K.J. Ptasinski, 2011. Biomass upgrading by torrefaction for the production of biofuels: a review. Biomass Bioenergy, 35: 3748-62.

Yuan, X., J. Tong, G. Zeng, H. Li and W. Xie, 2009. Comparative studies of products obtained at different temperatures during straw liquefaction by hot compressed water. Energy fuels, 23: 3262-3267.

Australian Journal of Basic and Applied Sciences, 10(17) Special 2016, Pages: 114-121

Sumathi, S., S.P. Chai, A.R. Mohamed, 2008. Utilization of oil palm as a source of renewable energy in Malaysia. Renewable and Sustainable Energy Review, pp: 2404-21.

Torres, S.S., W. Jomaa, F. Marc and J.R. Puiggali, 2010. *Causes of Color Changes in Wood during Drying.* Forestry Studies in China.

Tumulu, J.S., S.S okhansanj, J. Hess, C.T. Wright and D. Boardman, 2011. A review on biomass torrefaction process and product properties for energy applications. Industrial Biotechnology, 7: 384-401.