Journal of Cleaner Production xxx (2015) 1–5

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Improved yield and higher heating value of biochar from oil palm biomass at low retention time under self-sustained carbonization

Juferi Idris [a, b, c], Yoshihito Shirai [a], Yoshito Anduo [a], Ahmad Amiruddin Mohd Ali [a], Mohd Ridzuan Othman [d], Izzudin Ibrahim [e], Rafidah Husen [f], Mohd Ali Hassan [d, e, *]

[a] Department of Biological Functions and Engineering, Graduate School of Life Science and Systems Engineering, Kyushu Institute of Technology, 2-4 Hibikino, Wakamatsu-ku, Kitakyushu, Fukuoka 808-0196, Japan
[b] Faculty of Chemical Engineering, Universiti Teknologi MARA (UiTM), Sarawak, 94300, Kota Samarahan, Sarawak, Malaysia
[c] Faculty of Chemical Engineering, Universiti Teknologi MARA (UiTM), Malaysia, 40450, Shah Alam, Malaysia
[d] Department of Process and Food Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia
[e] Department of Bioprocess Technology, Faculty of Biotechnology and Biomolecular Sciences, Universiti Putra Malaysia (UPM), 43400 Serdang, Selangor, Malaysia
[f] Faculty of Applied Sciences, Universiti Teknologi MARA (UiTM), Sarawak, 94300, Kota Samarahan, Sarawak, Malaysia

A R T I C L E I N F O

Article history:
Received 4 March 2015
Received in revised form
6 May 2015
Accepted 7 May 2015
Available online xxx

Keywords:
Biochar
Charcoal
Heating value
Oil palm biomass
Self-sustained carbonization
Waste management and utilization

A B S T R A C T

Oil palm biochar with high yield and higher heating value under low energy requirement is required for improved waste management and utilization in the palm oil industry. This paper presents, a self-sustained carbonization of oil palm empty fruit bunch biomass, without internal heating element, which produced high biochar yield and higher heating value. Three different particle sizes of pressed-shredded oil palm empty fruit bunch biomass, i.e. below 29 mm, 30–99 mm and 100–150 mm, at 8–10% moisture content were used. The carbonization temperature was monitored and used as an indicator to stop the carbonization prior to harvesting. The maximum carbonization temperature recorded was 600 °C. In our previous report, harvested at 300 °C under uncontrolled exhausted air flow rate and found that the higher heating values obtained were 23.0–25.0 MJ/kg. However the biochar yield was only 14–16 %. In order to increase the yield of biochar, the exhaust air flow rate has been fixed at 36 m^3/hr by using an air suction blower to ensure uniform circulation and distribution of hot air from top to bottom before being discharged. The biochar was harvested when the temperature of the bed decreased to 500 °C. The particle size range from 100 to 150 mm produced the highest biochar yield of 26.0 ± 1.2% with higher heating value of 23.0–23.5 MJ/kg within 5–8 h retention time. The gaseous emissions were lower than permitted level set by the environmental authorities. The technology developed in this study should be used to improve the management and utilization of oil palm biomass towards a more sustainable palm oil industry.

1. Introduction

Biochar is attracting attention globally due to its unique potential for improved soil nutrient retention capacity, water holding capacity, increased crop yield and reduced greenhouse gas emissions (Kong et al., 2014). Zero-emission concept in the palm oil mill by using biochar for effluent treatment is attractive since biochar itself is non-chemical and the biomass is easily available within the palm oil industry (Othman et al., 2014). In addition, the use of biochar for heat and power generation has become more important due to the rapid depletion of fossil fuel. Production of biochar from oil palm biomass is gaining attention for improved waste management and utilization into value-added product (Kong et al., 2014).

Being the second largest oil palm producer in the world, Malaysia has enormous amount of oil palm biomass to produce biochar. Currently, there are 434 palm oil mills, producing an estimated 21 million tonnes of biomass residues annually in the form of oil palm empty fruit bunch (OPEFB), mesocarp fiber and palm kernel shell (MPOB, 2013; Talib et al., 2014). For each tonne of palm oil extracted, about 4 tonne of dry biomass is generated, of

* Corresponding author. Department of Bioprocess Technology, Faculty of Biotechnology and Biomolecular Sciences, Universiti Putra Malaysia (UPM), 43400 Serdang, Selangor, Malaysia. Tel.: +60 3 89466701; fax: +60 3 89467590.
E-mail address: alihas@upm.edu.my (M.A. Hassan).

http://dx.doi.org/10.1016/j.jclepro.2015.05.023
0959-6526/© 2015 Published by Elsevier Ltd.

which a third is available at the mill in the form of empty fruit bunch (OPEFB), palm kernel shell (PKS) and mesocarp fiber (MF) which are the residues from the fresh fruit bunch (FFB) (Sulaiman et al., 2011). Approximately 23% OPEFB alone is produced per tonne of fresh fruit bunch daily in the mills, at no additional cost for collection (Omar et al., 2011). In some mills, OPEFB are subjected to size reduction, such as pressing and shredding to recover oil and to reduce the bulkiness for easier transportation.

Currently, mesocarp fiber and palm kernel shell are used as in-house fuel to generate steam and energy for palm oil mills' requirement, while raw OPEFB is partly sold for mulching purpose (Yusoff, 2006). The utilization of OPEFB to produce biochar for fuel can improve the waste management and create a new business opportunity for the palm oil industry. Biochar production operated nearby the mill using pressed-shredded OPEFB can help reduce the transportation cost and this allows it to be produced at a lower cost. Hence, biochar produced can be sold as a new value-added product especially for fuel based on higher heating value and operating cost. The mesocarp fiber and palm kernel shell can still be used as in-house fuel to generate steam, without involving any major changes in the oil palm mill operation. However, high capital investment and high energy requirement especially for large scale production to convert this biomass into biochar with high yield and higher heating value biochar were the main obstacles (Idris et al., 2015). Therefore, an appropriate technology with reasonable cost and energy requirement, without compromising on the yield and quality of biochar produced, could overcome this problem.

The carbonization process with low temperature and low heating rate is an appropriate technology for biochar production (Demirbas, 2004). Higher heating value (HHV) and high yield are positively correlated with carbonization temperature (Hooi et al., 2009; Ronsse et al., 2013) as well as retention time, heating rate and material size (Abdullah and Sulaiman, 2013; Hooi et al., 2009; Sugumaran and Seshadri., 2009; Sukiran et al., 2011). Self-sustained carbonization to produce biochar using biomass feedstock without an internal electrical heating is unique due to its simplicity, ease of operation and reduced energy requirement (Idris et al., 2015).

Under self-sustained carbonization of OPEFB with uncontrolled exhausted air flow rate, comparable HHV biochar between 17 and 25 MJ/kg can be obtained at harvesting temperature of 300 °C (Idris et al., 2015). However, the yield of biochar was less than 16%. In this study, self-sustained carbonization at fixed exhausted air flow rate and harvesting temperature of 500 °C to produce high biochar yield with comparable HHV was conducted, for improved waste management and utilization of oil palm biomass to be implemented in the oil palm industry.

2. Materials and methods

2.1. Sample preparation

Pressed-shredded OPEFB was obtained and prepared according to Idris et al. (2015). The HHV values of raw OPEFB and biochar were analyzed three to five times from samples at five different locations in the reactor using a Parr 1261 bomb calorimeter. Three different particle sizes of below 29 mm, 30–99 mm and 100–150 mm OPEFB biomass were used in this study. The gaseous pollutants (CO_x, NO_x, SO_x, HCl and CH_4) and particulate matter below 10 mm (PM_{10}) were measured according to Idris et al. (2015) using a gas analyzer (MRU Vario Plus, Germany) and PM_{10} analyzer respectively.

2.2. Experimental setup

The detailed pilot-scale brick carbonization reactor specifications and carbonization operation procedure can be found in our previous study (Idris et al., 2015). However, the reactor was modified by installation of air suction blower to ensure the uniform circulation of hot air in the reactor from top to the bottom (Fig. 1). The exhausted gas flow rate discharged from the reactor was 36 m^3/hr. Once the carbonization commenced, valve 1 was set in open mode with valve 2 in closed mode. In this study, the harvesting temperature was used as an indicator to stop the carbonization process. OPEFB biochar was harvested when thermocouple 3 (T3) decreased to 500 °C and cooled down using sprayed water.

2.3. Analytical methods

A standard analytical test was done on the raw OPEFB and OPEFB biochar to determine moisture and volatile matter in the OPEFB samples. The thermal characteristics of dry OPEFB samples were analyzed with a computerized Perkin–Elmer Pyris 1 Thermogravimetric Analyzer and the ash content was determined following the standard method described by Nordin et al. (2013). The fixed carbon content was calculated by obtaining the difference. The ultimate analyses of Carbon (C), Hydrogen (H) and Nitrogen (N) content in OPEFB were determined using the CHNS/O Analyser (LECO CHNS932, USA) (Idris et al., 2013). The oxygen content was calculated by obtaining the difference. The chemical structure analysis (cellulose, hemicellulose and lignin content) in the OPEFB sample was analyzed via acid detergent fiber (ADF), neutral detergent fiber (NDF) and acid detergent lignin (ADL) methods analyses described by Omar et al. (2011). The HHVs of raw OPEFB and biochar were determined using a Parr 1261 bomb calorimeter (No. 242M).

3. Results and discussion

3.1. Characteristic of raw OPEFB biomass

The results of the proximate, ultimate, lignocellulose content and HHVs of raw OPEFB are shown in Table 1. All values are within the literature range except for fixed carbon which was slightly higher.

3.2. The effect of particle size and retention time on biochar yield and HHV at 500 °C harvesting temperatures

The temperature profiles in this study for all particle sizes tested were similar to those reported by Idris et el. (2015). Each

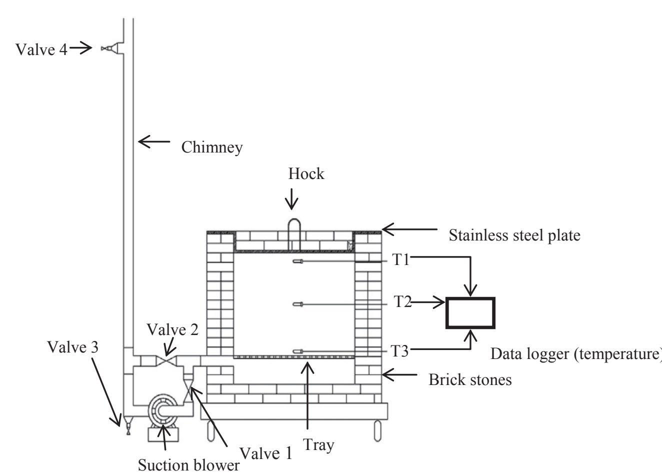

Fig. 1. Modified pilot scale self-sustained carbonization reactor with suction blower.

Please cite this article in press as: Idris, J., et al., Improved yield and higher heating value of biochar from oil palm biomass at low retention time under self-sustained carbonization, Journal of Cleaner Production (2015), http://dx.doi.org/10.1016/j.jclepro.2015.05.023

Table 1
Characteristics of raw oil palm empty fruit bunch biomass.

Analysis		This study	Literature references	
Proximate (%)[a]	Moisture	8.31 (±0.28)	6.36–8.75	(Abdullah and Gerhauser, 2008; Omar et al., 2011; Sugumaran and Seshadri., 2009; Xu et al., 2011)
	Ash	4.45 (±0.02)	2.8–7.54	(Abdullah and Gerhauser, 2008; Konsomboon et al., 2011; Omar et al., 2011; Sugumaran and Seshadri., 2009; Sun et al., 1999; Xu et al., 2011)
	Volatiles	67.59 (±1.15)	67.5–83.86	(Abdullah and Gerhauser, 2008; Konsomboon et al., 2011;
	Fixed carbon[b]	19.65	8.6–18.3	Omar et al., 2011; Sugumaran and Seshadri., 2009; Xu et al., 2011)
Ultimate (% dry, ash free)[a]	C	44.03 (±1.00)	40.7–71	
	H	6.4 (±0.16)	5.4–9.2	
	O[b]	47.75	10.6–47.8	
	N	1.65 (±0.27)	0–4	(Abdullah and Gerhauser, 2008; Konsomboon et al., 2011;
	S	0.17 (±0.02)	0–1.2	Omar et al., 2011; Xu et al., 2011)
Lignocellulose content (wt %)	Cellulose	38.73 (±4.28)	23.7–62.9	(Law et al., 2007; Omar et al., 2011; Sugumaran and Seshadri.,
	Hemi cellulose	19.55 (±2.51)	2.06–30.9	2009; Sun et al., 1999)
	Lignin	21.00 (±6.19)	14.2–29.2	
Higher heating value (HHV) (MJ/kg)[c]		17.74 (±1.40)	16.96–19.35	(Abdullah and Gerhauser, 2008; Konsomboon et al., 2011; Omar et al., 2011; Sugumaran and Seshadri., 2009)

[a] Dry basis.
[b] By difference.
[c] Idris et al. (2015).

carbonization test was repeated at least two times to ensure reproducibility. Table 2 shows the relationship between retention time, yield and higher heating value at harvesting temperature 500 °C of OPEFB biochar at different OPEFB biomass particle sizes, i.e. below 29 mm, 30–99 mm and 100–150 mm, under self-sustained carbonization with fixed exhaust air flow rate at 36 m^3/h. The biochar yield in this study showed a significant difference ($p < 0.05$) at different particle size and retention time. At harvesting temperature of 500 °C, the particle size range between 100 and 150 mm produced the highest biochar yield of 26.0 ± 1.2%.

For HHV, all particle sizes gave a comparable HHV between 22.9 and 24.9 MJ/kg, with no significant difference ($p > 0.05$). The particle size ranging of 100–150 mm can produce the highest biochar yield with comparable HHV range of 23.0–23.5 MJ/kg. Since OPEFB particle size of 100–150 mm was the original size obtained from the mill and was found suitable to produce an acceptable yield and higher heating value, it is beneficial to the palm oil industry that no further size reduction is needed and therefore less energy and cost are required. The retention time in self-sustained carbonization in this study is shorter compared to Idris et al. (2015), with higher yield, thus ensuring higher productivity.

3.3. Proximate and ultimate analysis of OPEFB biochar

The proximate and ultimate analyses of the biochar product for all particle sizes of OPEFB harvested at 500 °C are shown in Table 3. The proximate analysis results indicated that size reduction in this study did not affect the biochar quality. For particle size range of 100–150 mm, the proximate analysis results indicated that the ash content was slightly low, with high fixed carbon between 70.83 and 71.75%, which contributed to high HHV. The carbon contents obtained were between 64.33 ± 1.50–64.62 ± 1.77%, which similar to the 65% carbon content obtained by Sukiran et al. (2011). It is evident that through self-sustained carbonization under low energy requirement in this study, similar biochar properties can be produced compared to other studies using internal heating element which required more energy.

3.4. Comparison of retention time, biochar yield and HHV of OPEFB with other studies

Table 4 shows comparison of biochar yield, retention time and HHV of OPEFB biochar under self-sustained carbonization with other studies. The OPEFB biochar yield of 26.0 ± 1.2% and HHV between 23.0 and 23.5 MJ/kg obtained from particle size between 100 and 150 mm in this study under self-sustained carbonization can be considered high and comparable to Idris et al. (2015) and Sukiran et al. (2011). The effect of carbonization harvesting temperature influenced the retention time of all particle sizes tested. It was evident that harvesting at 500 °C gave shorter retention times between 310 and 460 min compared to harvesting at 300 °C for all particle sizes (Idris et al., 2015). Moreover, the usage of air suction blower to suck out exhausted air from the reactor had improved the hot air distribution before being discharged, and this accelerated the self-sustained carbonization process. The self-sustained carbonization whereby oil palm biomass is combusted to provide the heat for carbonization under limited oxygen is advantageous to the industry due to its simplicity, ease of operation and low energy requirement, making it a more preferable option for the palm oil industry for sustainable biochar production.

3.5. Gaseous emission

In this study, the gaseous pollutants and PM_{10} emission during self-sustained carbonization for OPEFB particle size between 100 and 150 mm were examined, since this size produced biochar with

Table 2
The effect of particle size and retention time on biochar yield at 500 °C harvesting temperature.

Particle size (mm)	Carbonization retention time (min)		Biochar yield (%)	Biochar higher heating value (HHV) (MJ/kg)	
	Run 1	Run 2		Run 1	Run 2
100–150	310	462	26.0(±1.2)[a]	23.5(±0.8)[d]	23.0(±0.1)[d]
30–99	635	460	24.2(±1.3)[b]	24.2(±0.1)[d]	24.5(±0.4)[d]
below 29	1145	1060	23.5(±0.9)[c]	22.9(±0.1)[d]	24.9(±0.7)[d]

Note: Biochar higher heating value (HHV) (mean ± SD, n = 3; different letters in the same column indicate significant difference ($p < 0.05$).

Table 3
Proximate and ultimate analyses of oil palm empty fruit bunch biochar at 500 °C harvesting temperature.

Particle size (mm)	Run	Proximate (%)[a]				Ultimate (% dry, ash free)[a]			
		Moisture	Ash	Volatiles	Fixed carbon[b]	C	H	O[b]	N
100–150	1	3.20(±1.20)	13.65 (±1.24)	12.32(±0.57)	70.83	64.33(±1.50)	3.68(±0.05)	30.41	1.58(±0.06)
	2	2.80(±1.56)	12.98 (±1.16)	12.47(±0.37)	71.75	64.62(±1.77)	3.65(±0.07)	30.17	1.56(±0.04)
30–99	1	3.00(±1.60)	13.66(±1.24)	12.44(±0.45)	70.90	63.40(±1.59)	3.27(±0.05)	31.56	1.77(±0.15)
	2	2.90(±1.80)	12.98(±1.16)	12.95(±0.55)	71.17	65.24(±0.73)	3.47(±0.37)	29.69	1.61(±0.02)
Below 29	1	3.30(±1.20)	13.25(±0.56)	12.50(±0.46)	70.95	63.92(±0.16)	3.52(±0.03)	30.88	1.68(±0.05)
	2	3.56(±0.12)	15.10(±0.23)	12.10(±0.68)	69.24	59.10(±1.85)	3.13(±0.09)	36.30	1.48(±0.04)

[a] Dry basis.
[b] By difference.

Table 4
Comparison of biochar higher heating value (HHV) and carbonization conditions on oil palm empty fruit bunch with other studies.

Combustor	Exhausted air flow	Internal energy source	Particle size	Harvesting temperature (°C)	Temperature (°C)	Retention time (min)	Biochar yield (%)	Biochar HHV (MJ/kg)	References
Pilot-scale brick	Fixed	No	100–150 mm	Decreased at 500	300–580	310–462	26.0 ± 1.2	23.0–23.5	This study
	Uncontrolled	No	30–99 mm	Decreased at 300	300–590	910–953	14–16	23.0–25.0	Idris et al. (2015)
Fluidized fixed bed	–	Yes	91–106 μm	–	300–700	Below 20	23–42	22.9–25.9	Sukiran et al. (2011)

the highest yield and HHV. The average concentration of CO_2, CO and CH_4 released during the carbonization process were 5.59 ± 1.20, 0.72 ± 0.31 and 0.39 ± 0.12% respectively, while the average NO_x and PM_{10} were 28.00 ± 1.41 ppm and 584.00 ± 14.84 mg/m^3 respectively. Sulphur dioxide (SO_2) and hydrogen chloride (HCl) were not detected in this study due to carbonization temperature below 700 °C, since conversion of sulphur into SO_2 could only occur with carbonization temperatures above 1200 °C (Hyung-Taek and Chun, 1998). The average gaseous pollutant emissions concentration in this study were similar to Idris et al. (2015). The concentration of NO_x, SO_2, HCl and PM10 values were lower than permitted level limits of air pollution emissions for incineration of municipal solid wastes (MSW) at 300 mg/m^3 set by Department of Environment (DOE), Malaysia (DOE, 2000).

4. Conclusion

Harvesting of OPEFB biochar when carbonization temperature decreased to 500 °C at the particle size range of 100–150 mm produced the highest yield of biochar of 26.0 ± 1.2% under self-sustained carbonization. The HHV of the biochar which was between 23.0 and 23.5 MJ/kg is comparable with other studies conducted under controlled temperature with internal heating elements. Biochar with acceptable higher heating value and high yield with low gaseous emission from raw OPEFB represents a high value-added product from oil palm biomass. The result from this study can increase the utilization of oil palm biomass waste in creating zero waste operation. The impact of this study can create a new business opportunity, for extra income and new employment not only for the oil palm industry, but also to the local community. We envisage that the oil palm industry will adopt this appropriate technology for the continuous sustainable development which addresses all the three pillars of sustainability, i.e. profit, people and planet.

Acknowledgment

The authors acknowledge the research grant provided by Japan International Cooperation Agency (JICA)-Japan Science and Technology Agency (JST)-SATREPS and Ministry of Education, Malaysia (Grant No. 6300156). The authors also thank Kyushu Institute of Technology (Kyutech), Japan, Universiti Putra Malaysia (UPM), Malaysia, Universiti Teknologi MARA (UiTM), Malaysia and Universiti Teknologi MARA (UiTM) Sarawak for their technical support towards this research.

References

Abdullah, N., Gerhauser, H., 2008. Bio-oil derived from empty fruit bunches. Fuel 87, 2606–2613.
Abdullah, N., Sulaiman, F., 2013. A comparison study on oven and solar dried empty fruit bunches. J. Environ. Earth Sci. 3, 145–156.
Demirbas, A., 2004. Effects of temperature and particle size on bio-char yield from pyrolysis of agricultural residues. J. Anal. Appl. Pyrolysis. 72, 243–248.
Hooi, K.K., Alimuddin, Z., Alauddin, Z., Ong, L.I.M.K., 2009. Laboratory-scale pyrolysis of oil palm pressed fruit fibres. J. Oil Palm. Res. 21, 577–587.
Kim, Hyung-Taek, Chun, Wongee, 1998. The particle size effect on the pollutant formation in pulverised caol combustion. Environ. Eng. Res. 3, 21–29.
Idris, J., Md Som, A., Musa, M., Ku Hamid, K.H., Husen, R., Muhd Rodhi, M.N., 2013. Dragon fruit foliage plant-based coagulant for treatment of concentrated latex effluent: comparison of treatment with ferric sulfate. J. Chem. 2013, 1–7.
Idris, J., Shirai, Y., Andou, Y., Mohd Ali, A.A., Othman, M.R., Ibrahim, I., Hassan, M.A., 2015. Self-sustained carbonization of oil palm biomass produced an acceptable heating value charcoal with low gaseous emission. J. Clean. Prod. 89, 257–261.
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. Renew. Sustain. Energy Rev. 39, 729–739.
Konsomboon, S., Pipatmanomai, S., Madhiyanon, T., Tia, S., 2011. Effect of kaolin addition on ash characteristics of palm empty fruit bunch (EFB) upon combustion. Appl. Energy. 88, 298–305.
Law, K.-N., Wan Daud, W.R., Ghazali, A., 2007. Morphological and chemical nature of fiber strands of oil Palm empty fruit Bunch (OPEFB). BioResources 2, 351–362.
MPOB, 2013. Oil Palm & the Environment. http://mpob.gov.my/en/palm-info/environment/520-achievements (accessed 02.07.14.).
Nordin, N.I.A.A., Ariffin, H., Andou, Y., Hassan, M.A., Shirai, Y., Nishida, H., Yunus, W.Z.W., Karuppuchamy, S., Ibrahim, N.A., 2013. Modification of oil palm mesocarp fiber characteristics using superheated steam treatment. Molecules 18, 9132–9146.
Omar, R., Idris, A., Yunus, R., Khalid, K., Aida Isma, M.I., 2011. Characterization of empty fruit bunch for microwave-assisted pyrolysis. Fuel 90, 1536–1544.
Othman, M.R., Hassan, M.A., Shirai, Y., Baharuddin, A.S., Ali, A.A.M., Idris, J., 2014. Treatment of effluents from palm oil mill process to achieve river water quality for reuse as recycled water in a zero emission system. J. Clean. Prod. 67, 58–61.
Ronsse, F., van Hecke, S., Dickinson, D., Prins, W., 2013. Production and characterization of slow pyrolysis biochar: influence of feedstock type and pyrolysis conditions. GCB Bioenergy. 5, 104–115.
Sugumaran, P., Seshadri, S., 2009. Evaluation of selected biomass for charcoal production. J. Sci. Ind. Res. 68, 719–723.
Sukiran, M.A., Kheang, L.S., Bakar, N.A., May, C.Y., 2011. Production and characterization of bio-char from the pyrolysis of empty fruit bunches. Am. J. Appl. Sci. 8, 984–988.
Sulaiman, F., Abdullah, N., Gerhauser, H., Shariff, A., 2011. An outlook of malaysian energy, oil palm industry and its utilization of wastes as useful resources. Biomass Bioenergy. 35, 3775–3786.

Sun, R., Tomkinson, J., Bolton, J., 1999. Effects of precipitation pH on the physico-chemical properties of the lignins isolated from the black liquor of oil palm empty fruit bunch fibre pulping. Polym. Degrad. Stab. 63, 195–200.

Talib, A.T., Mokhtar, M.N., Baharuddin, A.S., Sulaiman, A., 2014. Effects of aeration rate on degradation process of oil palm empty fruit bunch with kinetic-dynamic modeling. Bioresour. Technol. 169, 428–438.

Xu, R., Ferrante, L., Hall, K., Briens, C., Berruti, F., 2011. Thermal self-sustainability of biochar production by pyrolysis. J. Anal. Appl. Pyrolysis 91, 55–66.

Yusoff, S., 2006. Renewable energy from palm oil – innovation on effective utilization of waste. J. Clean. Prod. 14, 87–93.