



Note from the field

Self-sustained carbonization of oil palm biomass produced an acceptable heating value charcoal with low gaseous emission



Juferi Idris ^{a, b, c}, Yoshihito Shirai ^a, Yoshito Andou ^a, Ahmad Amiruddin Mohd Ali ^a, Mohd Ridzuan Othman ^e, Izzudin Ibrahim ^d, 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 Bioprocess Technology, Faculty of Biotechnology and Biomolecular Sciences, Universiti Putra Malaysia (UPM), 43400 Serdang, Selangor, Malaysia

^e Department of Process and Food Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia

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ABSTRACT

Charcoal production with higher heating value (HHV) requires high capital investment and high energy requirement for large scale production. In this study, charcoal production under self-sustained carbonization from oil palm biomass was proposed and tested at pilot scale, whereby temperature and exhaust gas flow rate were monitored but not controlled. This proposed system under self-sustained carbonization, whereby oil palm biomass is combusted to provide the heat for carbonization in inadequate oxygen is preferable to the industry due to its simplicity, ease of operation and low energy requirement. Moreover, the gaseous emissions are below the permitted level set by the environmental authorities. The considerable HHV obtained was between 23 and 25 MJ/kg with low gaseous emissions. The results obtained are acceptable and comparable to other studies on oil palm biomass conducted under controlled conditions with electrical heating elements.

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1. Introduction

The utilization of biomass as a biofuel with low sulphur and nitrogen creates less environmental pollution and fewer health risks than fossil fuel combustion. The application of biofuel helps to reduce the problem of gaseous pollutants emissions and their climate impact, particularly on issues related to greenhouse gases or global warming (Rousset et al., 2011). The palm oil industry generates biomass in the form of oil palm empty fruit bunch (OPEFB), mesocarp fibre and palm kernel shell (Sumathi et al., 2008). A typical palm oil mill produced 69,000 dry ton OPEFB per year (Yoshizaki et al., 2013). Therefore the palm oil industry has the potential to produce clean renewable energy from oil palm biomass. Furthermore, the biomass is produced daily at each mill,

with no additional cost for collection (Omar et al., 2011). Currently, only mesocarp fibres and palm kernel shell are used as fuel to generate steam and electricity for palm oil mills requirement (Yusoff, 2006), while raw OPEFB is partly sold for mulching purpose (Yoshizaki et al., 2013). Compared to mulching, conversion of raw OPEFB into charcoal for fuel can give 3.5 times higher value when sold as a fuel for power generation (Anuradda and Rangan, 2001; Menon et al., 2006).

Carbonization conducted in the absence or inadequate presence of oxygen to produce a high calorific value fuel is a promising technology for biomass utilization (Adam, 2009). Moderate carbonization temperatures between 300 and 700 °C produced good quality charcoal with HHV between 18 and 27 MJ/kg as fuel for power generation (Hooi et al., 2009). There have been several reports on the production of charcoal from different sizes of OPEFB with an HHV under controlled carbonization temperature using external energy sources, such as an electrical heating element or a furnace (Razuan et al., 2011; Sugumaran, 2009; Sukiran et al., 2011). The self-sustained carbonization, whereby oil palm biomass is combusted to provide the heat for carbonization in inadequate

* Corresponding author. Department of Bioprocess Technology, Faculty of Biotechnology and Biomolecular Sciences, Universiti Putra Malaysia (UPM), 43400 Serdang, Selangor, Malaysia. Tel.: +603 8946 6701; fax: +603 8946 7590.

E-mail address: alihak@upm.edu.my (M.A. Hassan).

oxygen to produce charcoal using biomass feedstock without an electrical heater is more preferable to the industry due to its simplicity, ease of operation and low energy requirement. Therefore, in this study, the application of self-sustained carbonization in a pilot scale for the production of considerable HHV of OPEFB charcoal with low gaseous emission was conducted.

2. Materials and methods

Pressed-shredded and dried OPEFB biomass was obtained from Seri Ulu Langat Palm Oil Mill, Dengkil, Selangor, Malaysia. The particle size of pressed-shredded OPEFB biomass was 100–150 mm. The samples were pulverised and sieved into a half range of 30–99 mm and a quarter size range below 29 mm using a Sima FG 560 × 450 heavy duty grinder. The carbonization process for each particle size was run at least twice to ensure reproducibility. The HHV values of raw OPEFB and charcoal were analyzed from three to five times, from five different locations in the reactor using a Parr 1261 bomb calorimeter.

Combustion of OPEFB biomass was conducted in a pilot-scale brick carbonization reactor, as shown in Fig. 1. The reactor was built with double walls of clay bricks (1000 mm × 1000 mm external dimension, 220 mm thick). The double walls of bricks stone were used to provide a natural insulation of the reactor (Adam, 2009). Approximately 30 kg of OPEFB was carbonized per batch of operation. The bed heights for the particle having sizes below 29 mm, 30–99 mm and 100–150 mm were 0.25 m, 0.40 m and 0.51 m, respectively. After the OPEFB sample was fed into the reactor, the fire was started manually at the top of the reactor using a portable propane gas burner for approximately 3–5 min. The cover of the reactor was then closed completely, and the carbonization temperature was self-sustained on its own using OPEFB

biomass as the fuel. All parts of the reactor, especially the stainless steel cover, were closed tightly to avoid any entrance of oxygen. The temperatures inside the reactor were monitored using three k-type thermocouples positioned at different heights from the bottom of the reactor, i.e., T1 (0.46 m), T2 (0.25 m) and T3 (0.04 m). A tray was installed 0.02 m from the bottom, so there is an empty space at the bottom of the reactor to circulate smoke before it can be discharged through the 3 m chimney. The temperatures were automatically recorded every 60 s using a data logger. The carbonization time was recorded once the temperature at T2 reached 300 °C (Spokas et al., 2012). The gas emission from the carbonization process was discharged through an upward stainless steel chimney pipe that was 0.07 m in diameter, and the exhaust gas flow rate was measured using a gas flow meter. The gaseous pollutants and particulate matter below 10 µm (PM₁₀) were measured at the top of the reactor chimney using a gas analyzer (MRU Vario Plus, Germany) and PM₁₀ analyser at every 30 min. The gaseous pollutants determined were CO_x, NO_x, SO_x, HCl and CH₄. The carbonization for each batch of the experiment was stopped using sprayed water once the temperature of the bed at T3 decreased below 300 °C. The charcoal product was removed from the reactor and dried to achieve a moisture content below 5%. The dried charcoal was weighed for a yield calculation and analysed for HHV. The experiments were repeated to ensure reproducibility.

3. Results and discussion

Fig. 2(a)–(c) shows the temperature profiles measured at different OPEFB particle sizes under self-sustained carbonization. Although three (3) thermocouples were used to monitor the temperature at different positions (top, middle and bottom) in the reactor throughout the tests, only temperatures at the middle and

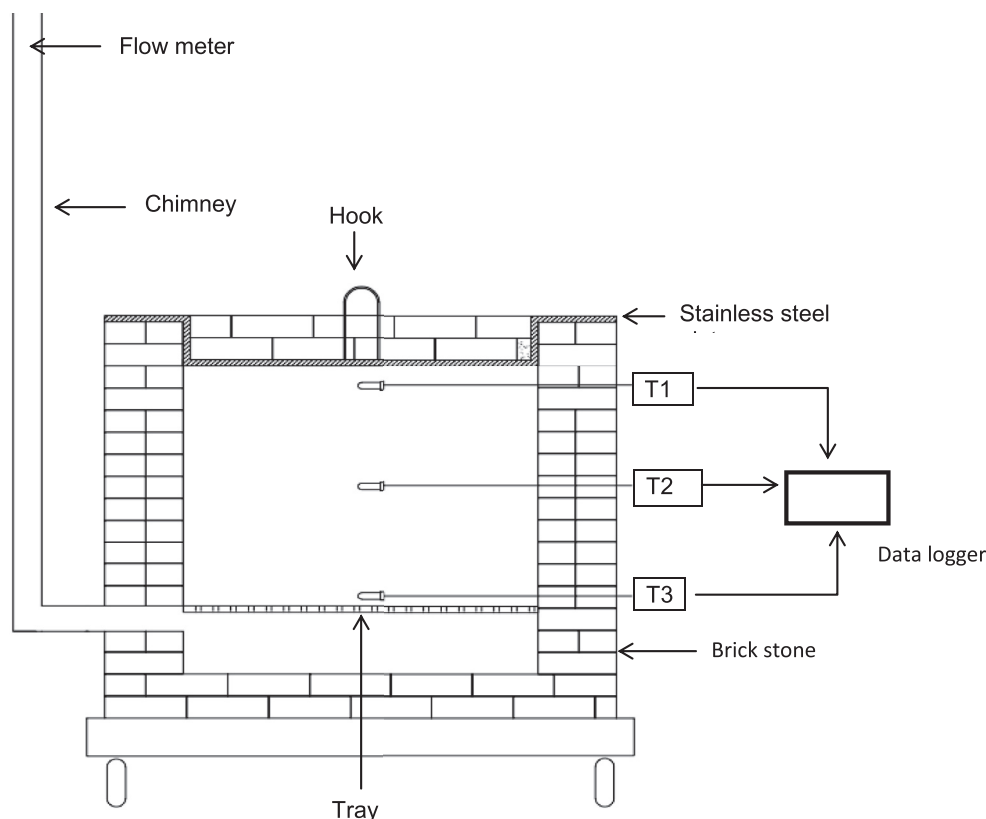


Fig. 1. Schematic diagram of the pilot-scale brick carbonization reactor.

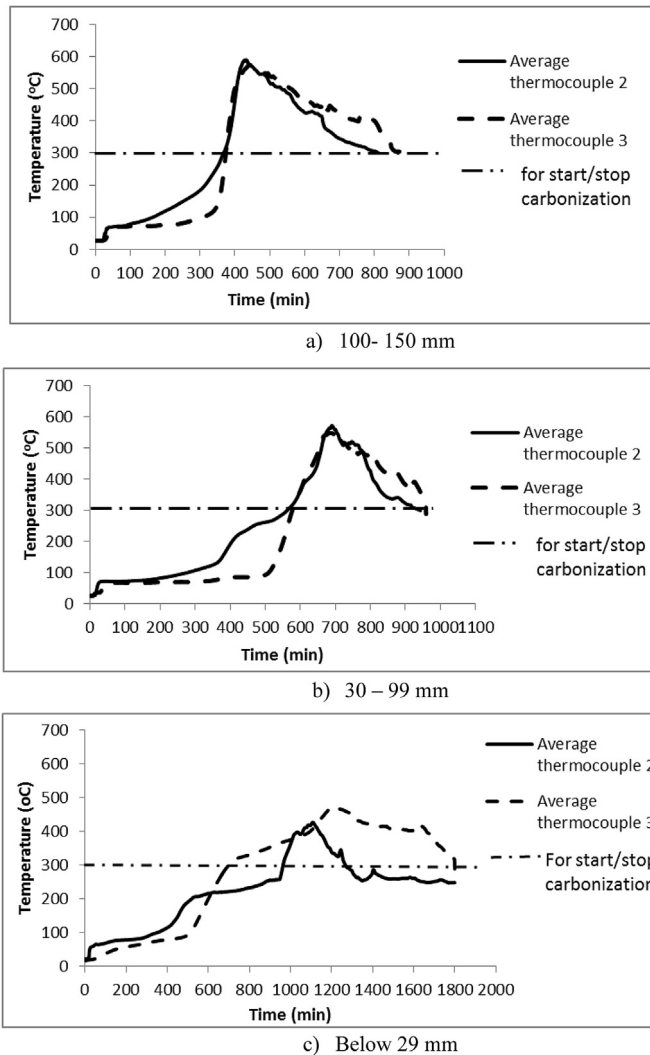


Fig. 2. Temperature profiles of OPEFB biomass under self-sustained carbonization at different particle sizes.

bottom were found necessary to represent the reactor temperature in the reactor due to different heights of bed material. Each temperature was taken from average of at least 2 runs of carbonization process. The temperature in the reactor gradually increased moments after the fire was introduced for all three particle sizes. Generally the temperatures increased as combustion moved towards the bottom of the reactor as shown in the all the figures, with thermocouple 2 reaching high temperature followed by

thermocouple 3. The particle size did not influence the maximum temperature, and the average maximum temperature was found to be in the range of 417–590 °C in all tests. However, it was obvious that the particle size influenced the carbonization period. As the particle size decreased, the bulk density increased and the carbonization time increased with exhaust gas flow rates of 23.0–25.8 m³/h (Table 1). As the particle size decreased, the carbonization retention time increased. This was due to the arrangement of the particle size effecting the hot air distribution in the reactor. Large particle size in the reactor shows loosely packed arrangement due to non-uniform particle size in the reactor, thus hot air easily passed through between the particles and faster hot air distribution gave short retention time of carbonization. For smallest particle size, below 29 mm, the arrangement was tightly packed with the OPEFB biomass, thus it was difficult for hot air to pass between the particles, this will take longer for hot air to be distributed in the reactor before discharged. The average carbonization temperatures were between 300 and 590 °C for all experiments which is an appropriate condition to produce charcoal. According to Spokas et al. (2012), temperatures ranging from 300 to 700 °C and long residence times, from minutes to hours, are suitable for good biochar production. In this study, the residence time ranged from 900 to 1900 min. However, long carbonization retention time process will not give good yield and quality of biochar. Moreover, the inconsistent carbonization temperature may have caused the low 17% charcoal yield in this study compared to other studies, and this is in an agreement with Sugumaran, (2009) who obtained decreasing OPEFB biochar yield as temperature of carbonization increased to 400 °C. Therefore, it is recommended to shorten the carbonization retention time in order to increase the yield and HHV of charcoal especially in real large scale capacity.

The HHV of charcoal at different particle sizes ranged from 20.46 to 25.03 MJ/kg. The highest charcoal HHV obtained was 23.32–25.03 MJ/kg at the intermediate particle size from 30 to 99 mm at carbonization temperature ranging from 300 to 570 °C. This result is in agreement with Sukiran et al. (2011), who obtained HHV in the range of 22.98–25.98 MJ/kg at temperatures of 300–600 °C under a controlled carbonization temperature and heating rate using a fluidized bed reactor with the same biomass. The major contributing factor to the considerable HHV in this study is the homogeneous OPEFB biomass after second-stage grinding, in comparison to the original 100–150 mm pressed-shredded OPEFB from the palm oil mill without grinding which produced a lower charcoal HHV of 20.46–20.94 MJ/kg. The original OPEFB biomass which was less homogeneous may have caused excess non-uniform hot air circulation in the reactor passing through the uneven particles, with a poor removal of volatile matter. On the other hand, for particle size below 29 mm, the low HHV charcoal between 20.90 and 21.02 MJ/kg was mainly due to much longer carbonization time, which turned the very fine particles into ash. The OPEFB

Table 1

Comparison of HHV and carbonization conditions of OPEFB charcoal with other studies.

Combustor	Particle size	Bulk density (kg/m ³)	Run	Average exhaust gas flow rates (m ³ /h)	Yield (%)	Charcoal HHV (MJ/kg)	References
Pilot-scale brick	Below 29 mm	120	1	25.4	11.7	20.90 (±0.40) ^a	This study
			2	23.1	11	21.02 (±0.30) ^a	
	30–99 mm	75	1	24.8	16.3	25.03 (±0.45) ^b	
			2	23.0	14.5	23.32 (±0.44) ^b	
	100–150 mm	59	1	25.8	12	20.46 (±0.73) ^c	
			2	23.5	10	20.94 (±0.33) ^c	
Muffle furnace	<1.8 mm	—	—	—	45.90	18.46	Sugumaran (2009)
Fluidized fixed bed	91–106 µm	—	—	—	25–28	25.98	Sukiran et al. (2011)

Raw OPEFB HHV = 17.74(±1.40) MJ/kg, charcoal HHV (mean ± SD, *n* = 3; letters in common indicate no significant difference (*p* > 0.05)).

charcoal HHV of 23.32–25.03 MJ/kg obtained from the 30–99 mm particle size in this study under self-sustained carbonization is considerable and comparable to Sukiran et al. (2011) who obtained a value of 22.98–25.98 MJ/kg under controlled carbonization, with an external energy source. The OPEFB charcoal fine powder obtained in this study is suitable to be transformed into a pellet or briquette. Furthermore, throughout the briquette production process, CO₂ emissions are totally compensated for by the environmental quality of raw material used (charcoal fines), as reported by Rousset et al. (2011).

In this study, only the gaseous pollutants and particulate matter emission during self-sustained carbonization for the intermediate OPEFB particle size between 30 and 99 mm were examined since this size produced charcoal with the highest HHV. Table 2 shows the average gaseous pollutant emissions concentration obtained from the carbonization of 30–99 mm OPEFB biomass under self-sustained carbonization temperature and exhaust gas flow rate, measured the moment the smoke was released from the chimney. It was found that the dominant gaseous pollutants in this study were CO₂, CO, NO, NO_x and CH₄, in agreement with Yan et al. (2005), based on their study on pyrolysis of palm oil wastes at temperature range 200–1200 °C. The finding was similar to the carbonization of wood using improved charcoal production system in a traditional kiln which produced CO₂, CH₄ and other active species such as NO_x (Adam, 2009). It was found that the concentrations of CO₂, NO, NO_x and CH₄ released during the carbonization process in this study were between 3.2 and 3.6 %, 41–65 ppm, 52–66 ppm and 0.22–0.29 %, respectively.

The release of NO_x was from the conversion of nitrogen from the OPEFB biomass during the carbonization process. A similar observation was reported by Liang et al. (2008) and Nussbaumer (2003) with other biomass. Sulphur dioxide (SO₂) and hydrogen chloride (HCl) were not detected in this study. This is in agreement with the study by Adam (2009) where no emission of SO₂ and HCl were reported. Razuan et al. (2010) also reported that SO₂ and HCl concentrations were lower than 0.05 ppm under controlled temperature and exhaust gas flow rate. In this study, the NO, NO_x, SO₂ and HCl values were much lower than permitted level limits of air pollution emissions for incineration of municipal solid wastes (MSW) at 300 mg/m³ set by Department of Environment (DOE), Malaysia (DOE, 2000). The release of CH₄ was from the conversion of methanol from OPEFB charcoal as previously reported by Kamarudin et al. (2013).

From Table 2, the average PM₁₀ released from the chimney was between 557 and 562 mg/m³, which was below the permitted level under environmental quality (clean air) regulations 1978, part v – air impurities regulation 25, Standard A (DOE, 2000), i.e. not exceeding 600 mg/m³. Table 2 shows the comparison of gaseous

pollutant components released from the carbonization of OPEFB biomass with other studies. The gaseous pollutant emissions from OPEFB carbonization charcoal in this study can be considered low when compared to Razuan et al. (2011). In our study, the gaseous pollutant emission is low despite producing considerable HHV of 21–25 MJ/kg compared with other studies conducted under controlled temperature and exhaust gas flow rate.

4. Conclusion

Carbonization of OPEFB biomass under self-sustained temperature and exhaust gas flow in a pilot-scale brick reactor produced an acceptable and comparable HHV with other studies conducted under controlled temperature with external energy sources, making it a more preferable option for the palm oil industry. It is observed that the emission of CO₂, CO, NO, NO_x and CH₄ were low compared with other oil palm biomass carbonization under controlled temperature and exhaust gas flow rate using external electrical sources. Moreover, the average PM₁₀ and NO_x were well below permitted levels of air pollution emissions, while SO₂ and HCl were not detected.

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References

- Adam, J.C., 2009. Improved and more environmentally friendly charcoal production system using a low-cost retort-kiln (Eco-charcoal). *Renew. Energy* 34, 1923–1925.
- Anuradda, G., Rangan, B., 2001. Biomass pyrolysis for power generation - a potential technology. *Renew. Energy* 9–14.
- Department of Environment (DOE), Malaysia, 2000. Environmental quality (clean air) regulations 1978. http://cp.doe.gov.my/cpvc/wpcontent/uploads/2011/04/Regulations/Environmental_Quality/Clean_Air.pdf (accessed June 2012).
- 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.
- Kamarudin, S.K., Shamsul, N.S., Ghani, J.A., Chia, S.K., Liew, H.S., Samsudin, A.S., 2013. Production of methanol from biomass waste via pyrolysis. *Bioresour. Technol.* 129, 463–468.
- Liang, L., Sun, R., Fei, J., Wu, S., Liu, X., Dai, K., Yao, N., 2008. Experimental study on effects of moisture content on combustion characteristics of simulated municipal solid wastes in a fixed bed. *Bioresour. Technol.* 99, 7238–7246.
- Menon, N.R., Ab Rahman, Z., Abu Bakar, N., 2006. Empty fruit bunches evaluation: mulch in plantation vs fuel for electricity generation. *Oil Palm Ind. Econ. J.* 3, 15–20.
- Nussbaumer, T., 2003. Combustion and co-combustion of biomass: fundamentals, technologies, and primary measures for emission reduction. *Energy Fuels* 17, 1510–1521.
- 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.
- Razuan, R., Chen, Q., Finney, K.N., Russell, N.V., Sharifi, V.N., Swithenbank, J., 2011. Combustion of oil palm stone in a pilot-scale fluidised bed reactor. *Fuel Process Technol.* 92, 2219–2225.
- Razuan, R., Chen, Q., Zhang, X., Sharifi, V., Swithenbank, J., 2010. Pyrolysis and combustion of oil palm stone and palm kernel cake in fixed-bed reactors. *Bioresour. Technol.* 101, 4622–4629.
- Rousset, P., Caldeira-Pires, A., Sablowski, A., Rodrigues, T., 2011. LCA of eucalyptus wood charcoal briquettes. *J. Clean. Prod.* 19, 1647–1653.
- Spokas, K.A., Cantrell, K.B., Novak, J.M., Archer, D.W., Ippolito, J.A., Collins, H.P., Boateng, A.A., Lima, I.M., Lamb, M.C., McAloon, A.J., Lentz, R.D., Nichols, K.A., 2012. Biochar: a synthesis of its agronomic impact beyond carbon sequestration. *J. Environ. Qual.* 41, 973–989.
- Sugumaran, P.S.S., 2009. Evaluation of selected biomass for charcoal production. *J. Sci. Ind. Res.* 68, 719–723.

Table 2

The gaseous pollutant emissions concentration.

Average gaseous emission concentration	This study	Razuan et al. (2011)	Standard limit concentration
CO ₂ (%)	3.2–3.6	9.15–15.11	300 mg/m ^{3a}
CO (%)	0.51–0.53	0.08–0.19	
CH ₄ (%)	0.22–0.29	–	
SO ₂ (ppm)	ND	0.02–0.05	600 mg/m ^{3b}
HCl (ppm)	ND	0.02–0.03	
NO (ppm)	41–65	162–238	
NO _x (ppm)	51–66	–	
PM ₁₀ (mg/m ³)	557–562	–	

ND = Not detected during carbonization.

^a Environmental quality (clean air) regulations 1978, part v – air impurities regulation 25, standard A, DOE, Malaysia.

^b Air pollution emissions for incineration of MSW, DOE Malaysia.

- 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.
- Sumathi, S., Chai, S.P., Mohamed, A.R., 2008. Utilization of oil palm as a source of renewable energy in Malaysia. *Renew. Sustain Energy Rev.* 12, 2404–2421.
- Yan, R., Yang, H., Chin, T., Liang, D.T., Chen, H., Zheng, C., 2005. Influence of temperature on the distribution of gaseous products from pyrolyzing palm oil wastes. *Combust. Flame* 142, 24–32.
- Yoshizaki, T., Shirai, Y., Hassan, M.A., Baharuddin, A.S., Raja Abdullah, N.M., Sulaiman, A., Busu, Z., 2013. Improved economic viability of integrated biogas energy and compost production for sustainable palm oil mill management. *J. Clean. Prod.* 44, 1–7.
- Yusoff, S., 2006. Renewable energy from palm oil – innovation on effective utilization of waste. *J. Clean. Prod.* 14, 87–93.