IOSR Journal of Engineering (IOSRJEN) **www.iosrjen.org**
ISSN (e): 2250-3021, ISSN (p): 2278-8719
Vol. 06, Issue 01 (January. 2016), ||V3|| PP 51-57

Moisture Content and Thermal Analysis of Malaysia Biomass Waste

Chong KokHing[1], Law PuongLing[2], Rigit Andrew Ragai Henry[3], Baini Rubiyah [4], Shanti Faridah Saleh[5]

[1]*Faculty of Engineering, Computing and Science, Swinburne University of Technology Sarawak Campus, Malaysia*
[2] *Department of Civil Engineering, Faculty of Engineering, Universiti Malaysia Sarawak, Malaysia*
[3]*Department of Mechanical Engineering, Faculty of Engineering, Universiti Malaysia Sarawak, Malaysia*
[4]*Department of Chemical Engineering and Energy Sustainability, Faculty of Engineering, Universiti Malaysia Sarawak, Malaysia,*
[5]*Lecturer, Department of Chemical Engineering and Energy Sustainability, Faculty of Engineering, Universiti Malaysia Sarawak, Malaysia,*

Abstract: **-** Moisture content and thermal properties of the selected biomass, such as oil palm kernel shell (OPKS) and wood chips, were carried out with Binder drying oven and Shimadzu DTG-60H thermal analyser accordingly. The moisture content of the selected wood chips (16.2 ± 1.1 wt. %.) is higher than selected oil palm kernel shell (11.7 ± 0.1 wt. %). Both selected biomass undergo four distinguish stages; namely, drying, pyrolysis, gasification and combustion. The average pyrolysis temperature range for OPKS and wood chips samples are 183.33 – 300.00℃ and 116.67 – 260.00℃, respectively. The average gasification temperature range of OPKS and wood chips samples are 300.00 – 373.33℃ and 260.00 – 365.00℃, respectively. The average combustion temperature range of OPKS and wood chips samples are 373.33 – 900.00℃ and 365.00 – 900.00℃, respectively. The findings show that there may be an important implication in choosing an appropriate combustion treatment method with regards to biomass waste.

Keywords: - *Combustion process, Oil palm kernel shell, Thermal property, Thermogravimetric analysis, Wood chips*

I. INTRODUCTION

Biomass energy can play an important role in reduce air pollutants and greenhouse gases. Due to its limited technology and abundance of biomass resource, third world countries rely heavily on biomass as source of prime energy. Even in developed countries, are rapidly establishing alternatives to replace fossil fuel through biomass [1]. As a result of continuous research and development, it can be foreseen that biomass energy likely to provide a cost-effective energy, while reducing the greenhouse gases. For example, many research on convert biomass energy to generate electricity and biogas for combustion [2]. In the 15 Member States of the European Union, approximately 1.4% of electricity is produced through biomass energy [3].

Malaysia is the world second palm oil producing country, follow by Thailand, Colombia and Nigeria [4]. Malaysia's palm oil production has an increase of 612% from 1980 (2.5 million tons) to 2009 (17.8 million tons). However, the co-products, consisting of fronds, trunks, empty fruit bunches, palm fibers and shells, are not utilized fully and are not exploited commercially [5]. Wood waste in Malaysia is found mostly in logging industries. In the first two months on 2009, Malaysia had profited of more than RM 202 million through logging activities [6]; consequently, tremendous amount of wood waste that, can raise sensitive environmental disposal issues.

The objective of this study was to analyze the events taking place during the combustion of the selected biomass. The burning profiles of biomass would determine the sequence of stage and characterizing the thermal behaviour. In this experiment, thermal analysis—thermogravimetry analysis (TGA) technique—was used to obtain the thermal behaviour of the selected biomass. Thermal analysis is an analysis of a change in a sample property, which is related to an appoint temperature modification [7].

Suzana *et al*. examined the thermal decomposition of Malaysia OPKS in the presence of steam and catalyst with thermogravimetric analyser-gas chromatography (TGA-GC). Their results showed that CO_2 concentration was reduced with addition of steam [8]. The authors, Abdullah, Sulaiman, and Gerhauser, investigated the thermal degradation behaviour of Malaysia oil palm empty fruit bunches with thermogravimetric analysis (TGA) [9]. Sulaiman and co-workers analysed the thermal event of Malaysia oil palm trunk and mixed tropical wood residue in combustion process with thermogravimetric analysis-mass spectrometry (TG-MS) [10]. Three events were identified: evaporation, devolatilization, and combustion.

Experiments on combustion characteristics toward wood pallets in Poland were conducted with thermogravimetric analysis (TG, DTG and DTA), the observed TG-MS gave quick assessment of the fuel combustion characterization [11]. Che *et al*. studied the combustion characteristics of China candlenut wood, and they found that the DTG data in agreement with the outcome of proximate analysis [12]. The authors, Luo, Xiao, Hu, Liu, and Guan, studied the combustion characteristics of pine sawdust in Wuhan City (China) with thermogravimetric analysis (TG-DTG) and they observed that oxygen enrichment could reduce burning time and improve combustion activity of biomass [13].

There are many published articles on the thermal analysis for biomass samples pyrolysis [14]–[22]; however, publications on the combustion of Malaysia oil palm kernel shell (OPKS) and wood chips using TGA are limited.

During biomass combustion, several thermal events takes place, which may influence toxic metals release into the environment. The chemical/physical form and concentration of these compounds depend on the composition of the solid residues and the combustion conditions [23]; thus, the knowledge of the possible thermal event happened during solid residue combustion is crucial, as it may improve the result by controlling the process. In this research, combustion behaviour of biomass waste known as oil palm kernel shell and wood chips was investigated using TGA technique.

II. MATERIAL AND METHOD

About 200 kg of fresh OPKS was collected from Bau Palm Oil Mill Sdn. Bhd. The average size of the OPKS measured 10.4 mm (width) by 4.8 mm (thick) by 12.8 mm (length). The wood chips were collected from a furniture factory at Kota Samarahan. Each sample was mixed, divided and covered to avoid adulteration. Moisture content of the sample investigated was determined according to the British Standard EN 1477-2:2009 [24] with Binder drying oven with natural convection. The size of the investigated sample was grinded to (1.0 ± 0.1) mm, and the weight at all time is about 200.0 g.

The moisture content, M_{ar}, of the investigated sample, as received, expressed as a percentage by mass with the following equation (1). The result is reported on a wet basis.

$$M_{ar} = \frac{(m_2 - m_3) + m_4}{(m_2 - m_1) + m_4} \, x\, 100 \qquad (1)$$

Where M_{ar} is the moisture content in the sample as received, m_1 is the mass in g of the empty drying container, m_2 is the mass in g of the drying container and sample before drying, m_3 is the mass in g of the drying container and sample after drying, m_4 the mass in g of the moisture associated with the packing.

There are five repetitions of the above procedure from the collected bulk sample.

In addition to the moisture content of the sample, thermal property of the sample was determined by Shimadzu DTG-60H thermal analyser. The selected biomass samples were conducted with Alumina as cell; air flow rate at 60 ml/min; sample weight at 20 mg; and temperature rate at 10^{o}C/min from 28^{o}C until 900^{o}C was achieved. Data of thermal analysis are recorded on-line using TA-60WS. It provides differential thermal analysis (DTA) and measurement of thermogravimetry analysis (TGA) on a sample. Thermogravimetry (TGA) is a technique that monitors the sample mass as a function of temperature when the sample is subjected to a controlled temperature [7]. There are three repetitions of thermal analysis on each sample and the experiments showed a good reproducibility.

III. RESULT AND DISCUSSION

This section presents the results in two parts. The first part present the moisture content of selected biomass sample and the second part present the thermal properties of selected biomass sample.

3.1 Moisture content of selected biomass sample

The moisture contents of the selected biomass samples are shown in Table 1 and Fig. 1. Oil palm kernel shell recorded moisture content of 11.7 $\pm$ 0.1 wt. %, while wood chip recorded moisture content of 16.2 $\pm$ 1.1 wt. %. Moisture content of the selected wood chips (16.2 $\pm$ 1.1 wt. %.) is higher than selected oil palm kernel shell (11.7 $\pm$ 0.1 wt. %). There was suitable moisture content (< 20 wt. %) for effective drying, as suggested by EU [25]. The results of oil palm kernel shell correlate well with Zafar [26] and Dagwa *et al* [27]. Moisture content of the selected wood chip, which is higher than the oil palm kernel shell, might be attributed to its morphology, which contains relatively higher moisture content and/or being exposed to rain [28].

Table 1: Average and standard deviation in moisture content of investigated biomass samples

Sample	Average (wt. %)	Standard deviation
Oil palm kernel shell	11.7	0.1
Wood chip	16.2	1.1

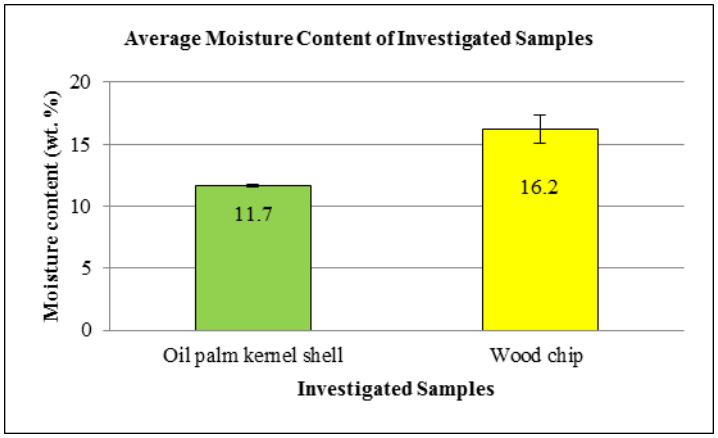

Figure 1: Average moisture content of investigated biomass samples

3.2 Thermal properties of selected biomass sample

Tables 2 – 7 and Fig. 2, 4, and 6 illustrate the thermal analysis outcome of the investigated OPKS and wood chips. The OPKS and wood chips begin to decompose at about 28^{o}C and would turn into ash completely at about 900^{o}C. It was observed that all three samples of OPKS and wood chips undergo 4 stages of transition. This correlated well with the theory of biomass combustion for drying, pyrolysis, gasification and combustion [29].

An endothermic process is observed in the early stage, which represents the drying process (Fig. 3 and 5). The average drying temperatures of OPKS and wood chips are 28.00 – 183.33^{o}C and 28.00 – 116.67^{o}C**,** respectively (Table 6). In Table 7 and Fig. 6, the weight loss of OPKS in the drying process consists of the highest percentage (14.601 %) compared to wood chips (12.352%). Drying occurs in two stages: the first stage is known as the constant drying rate, which is the evaporation of water on the biomass exterior; the second stage is known as the falling drying rate and is governed by the rate of diffusion within the biomass sample itself as water travels along a moisture gradient from the center towards its surface [30, 31]. Fyhr and Rasmuson discovered that the drying time is affected significantly by the dimension of the wood chips. The total drying time increased linearly with thickness as well as to the square root of the length as OPKS is at least 0.5 orders of magnitude larger than wood chips [32].

After the drying process, the investigated biomass samples proceeded with pyrolysis, gasification and combustion processes which can be attributed to the decomposition of cellulose, hemicellulose and lignin component in the biomass [33]. According to the literature, the hemicellulose starts to degrade at 220^{o}C, cellulose decomposes at temperatures greater than 300^{o}C, while lignin degrades slowly in the broader temperature range [34]. This finding was confirmed by Mahanim *et al.* who recorded that hemicellulose starts to degrade at 250 – 320^{o}C, cellulose pyrolysis at temperature range of 320 – 380^{o}C and while lignin decomposes slowly throughout the whole temperature range of room temperature up to 900^{o}C [35]. Thus, the decomposition of hemicellulose is responsible for the pyrolysis process. The decomposition of cellulose contributes to the gasification process, and decomposition of lignin accomplishes the combustion process. The average pyrolysis temperature of OPKS and wood chips samples are 183.33 – 300.00^{o}C and 116.67 – 260.00^{o}C**,** respectively (Table 6). The average gasification temperature of OPKS and wood chips samples are 300.00 – 373.33^{o}C and 260.00 – 365.00^{o}C**,** respectively. The average combustion temperature of OPKS and wood chips samples are 373.33 – 900.00^{o}C and 365.00 – 900.00^{o}C**,** respectively.

The results may have significant implication in determine an appropriate treatment method on biomass residues; for example, during the primary stage of the biomass combustion, it is necessary to increase the mixing ratio between the biomass and oxygen to avoid the presence of unburned hydrocarbons and carbon monoxide. Similarly, to control the formation of desired ash and optimum combustion/cooling conditions should be determined [36].

Table 2: Thermal analysis results of OPKS

Sample	Drying temperature (°C)	Pyrolysis temperature (°C)	Gasification temperature (°C)	Combustion temperature (°C)
OPKS 1	28.00 – 190.00	190.00 – 305.00	305.00 – 380.00	380.00 – 900.00
OPKS 2	28.00 – 190.00	190.00 – 295.00	295.00 – 370.00	370.00 – 900.00
OPKS 3	28.00 – 170.00	170.00 – 300.00	300.00 – 370.00	370.00 – 900.00
Average	28.00 – 183.33	183.33 – 300.00	300.00 – 373.33	373.33 – 900.00

Table 3: Weight loss (%) of OPKS vs process

Sample	Drying process (%)	Pyrolysis process (%)	Gasification process (%)	Combustion process (%)	Total weight loss (%)
OPKS 1	15.590	20.060	22.885	23.740	82.275
OPKS 2	14.955	17.835	24.755	23.790	81.335
OPKS 3	13.262	19.200	23.614	17.429	73.505
Average	14.601	19.032	23.751	21.653	79.037

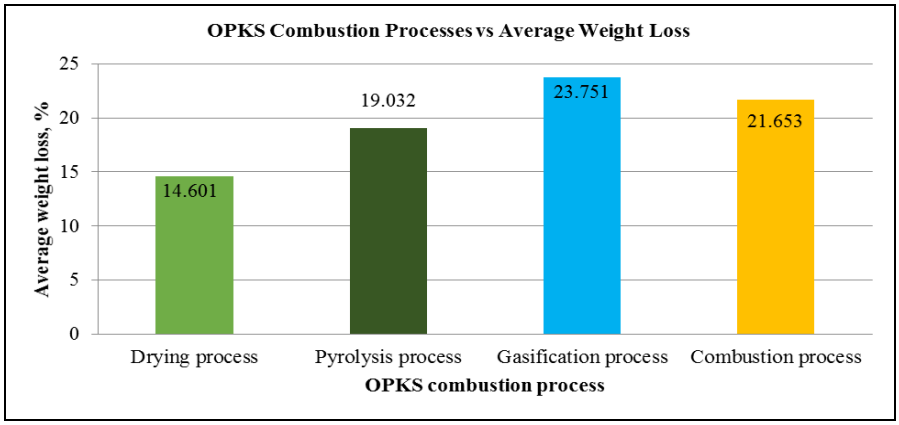

Figure 2: OPKS combustion process *vs* average weight losses

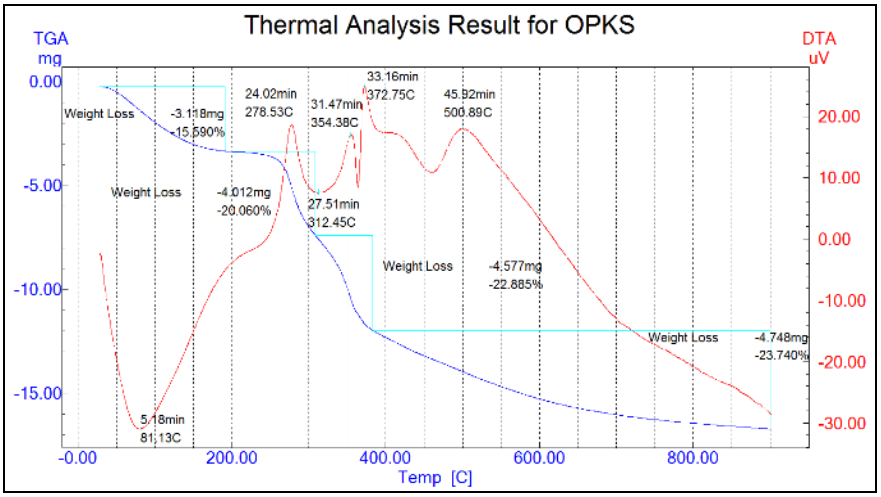

Figure 3: Thermal analysis result of OPKS sample

Table 4: Thermal analysis of the wood chips

Sample	Drying temperature (℃)	Pyrolysis temperature (℃)	Gasification temperature (℃)	Combustion temperature (℃)
Wood chips-1	28.00 – 120.00	120.00 – 260.00	260.00 – 370.00	370.00 – 900.00
Wood chips-2	28.00 – 120.00	120.00 – 255.00	255.00 – 360.00	360.00 – 900.00
Wood chips-3	28.00 – 110.00	110.00 – 265.00	265.00 – 365.00	365.00 – 900.00
Average	28.00 – 116.67	116.67 – 260.00	260.00 – 365.00	365.00 – 900.00

Table 5: Weight loss (%) of wood chips vs respective processes

Sample	Drying process (%)	Pyrolysis process (%)	Gasification process (%)	Combustion process (%)	Total weight loss (%)
Wood chips-1	11.957	2.924	48.700	14.290	77.871
Wood chips-2	13.070	2.805	44.530	30.220	90.625
Wood chips-3	12.029	4.643	48.405	33.290	98.367
Average	12.352	3.457	47.212	25.933	88.954

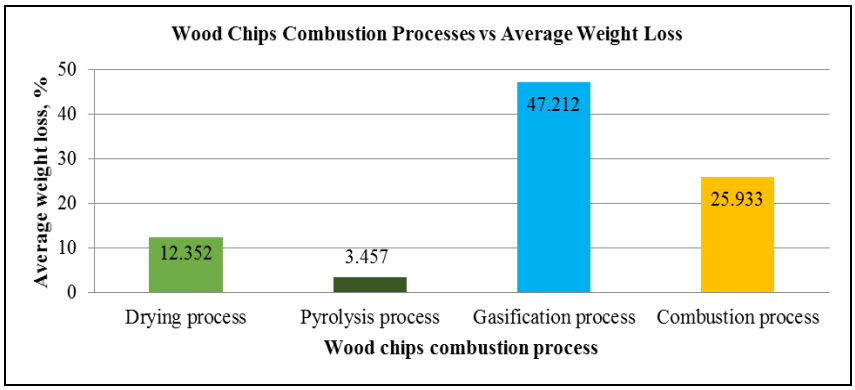

Figure 4: OPKS combustion processes *vs* average weight loss

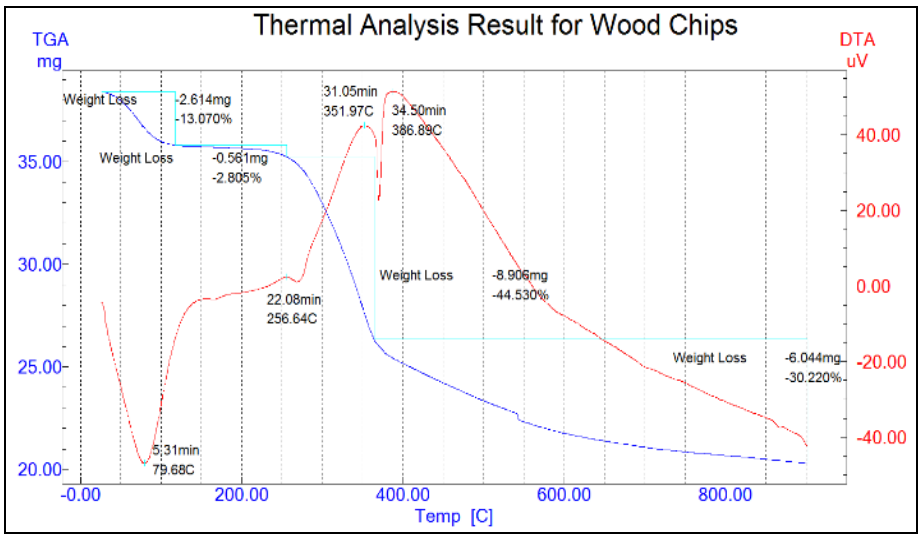

Figure 5: Thermal analysis result of wood chip sample

Table 6: Thermal analysis of OPKS and wood chips

Sample	Average drying temperature (℃)	Average pyrolysis temperature (℃)	Average gasification temperature (℃)	Average combustion temperature (℃)
OPKS	28.00 – 183.33	183.33 – 300.00	300.00 – 373.33	373.33 – 900.00
Wood chips	28.00 – 116.67	116.67 – 260.00	260.00 – 365.00	365.00 – 900.00

Table 7: Average weight loss of OPKS and wood chips

Sample	Drying process (%)	Pyrolysis process (%)	Gasification process (%)	Combustion process (%)	Total weight loss (%)
OPKS	14.601	19.032	23.751	21.653	79.037
Wood chips	12.352	3.457	47.212	25.933	88.954

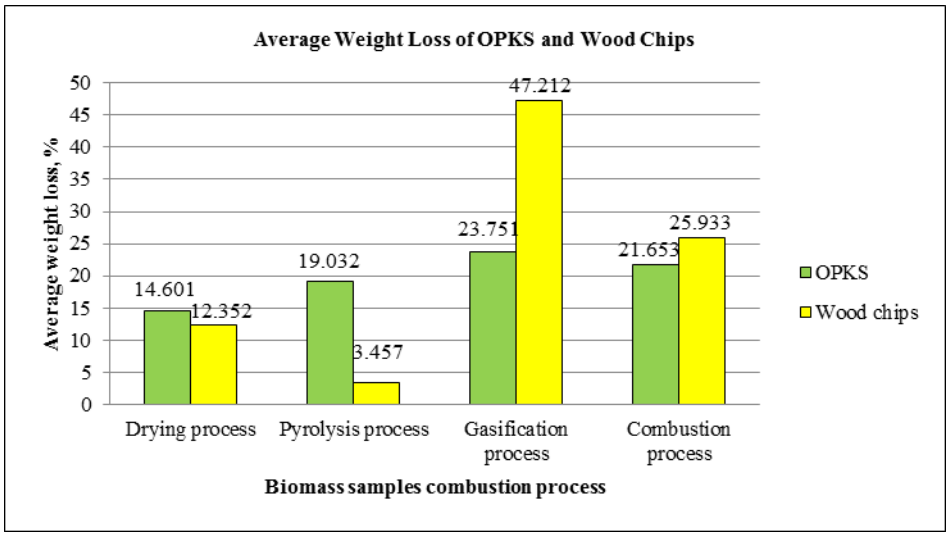

Figure 6: Average weight loss of OPKS and wood chips for biomass combustion process

IV. CONCLUSION

This study presents the results of thermal analysis of Malaysia biomass waste. Results showed that OPKS recorded moisture content of 11.7 $\pm$ 0.1 wt. %, while wood chip recorded moisture content of 16.2 $\pm$ 1.1 wt. %. The OPKS and wood chips samples would undergo four distinguish stages, e.g. drying, pyrolysis, gasification and combustion. The average pyrolysis temperature range for OPKS and wood chips samples are 183.33 – 300.00℃ and 116.67 – 260.00℃. The average gasification temperature range of OPKS and wood chips samples are 300.00 – 373.33℃ and 260.00 – 365.00℃, respectively. The average combustion temperature range of OPKS and wood chips samples are 373.33 – 900.00℃ and 365.00 – 900.00℃, respectively.

V. ACKNOWLEDGEMENTS

Authors acknowledge the funding provided by Zamalah Siswazah (UNIMAS), and MyBrain Kementerian Pengajian Tinggi. In addition, authors acknowledge the technical help of the technicians from Chemical Engineering and Energy Sustainability, UNIMAS.

REFERENCES

[1] A. Demirbas, "Potential applications of renewable energy sources, biomass combustion problems in boiler power systems and combustion related environmental issues," *Prog. Energy Combust. Sci.*, vol. 31, no. 2, pp. 171–192, Jan. 2005.

[2] M. Dogru, C. R. Howarth, G. Akay, B. Keskinler, and A. A. Malik, "Gasification of hazelnut shells in a downdraft gasifier," *Energy*, vol. 27, no. 5, pp. 415–427, May 2002.

[3] A. Bauen, J. Woods, and R. Hailes, "Bioelectricity Vision: Achieving 15% Electricity from Biomass in OECD Countries by 2020," London, 2004.

[4] Mundi, "Palm Oil Production by Country in 1000 MT," 2014. [Online]. Available: http://www.indexmundi.com/agriculture/?commodity=palm-oil&. [Accessed: 13-Mar-2014].

[5] S. M. Y. Kamaruzzan and Y. Baharuddin, "Renewable energy - Resources and applications in Malaysia." Pusat Tenaga Malaysia, Kajang, 2000.

[6] DOS, "Malaysia Export Of Major Timber Products (January - February 2009)," 2009. .

[7] W. Hemminger and S. . Sarge, *Handbook of thermal analysis and calorimetry*. The Netherlands: Elsevier Science B.V., 1998, p. 8.

[8] Y. Suzana, K. Zakir, M. Melati, R. Anita, M. Taufiq, S. Shahidah, M. Fatiha, S. Eda, and Abrar, "Effect of steam and catalyst on palm oil waste thermal decomposition for hydrogen production," *Res. J. Chem. Environ.*, vol. 15, no. 2, pp. 466–472, 2011.

[9] N. Abdullah, F. Sulaiman, and H. Gerhauser, "Characterisation of Oil Palm Empty Fruit Bunches for Fuel Application," vol. 22, no. 1, pp. 1–24, 2011.

[10] N. Aghamohammadi, N. M. Nik Sulaiman, and M. K. Aroua, "Combustion characteristics of biomass in SouthEast Asia," *Biomass and Bioenergy*, vol. 35, no. 9, pp. 3884–3890, Oct. 2011.

[11] A. Magdziarz and M. Wilk, "Thermal characteristics of the combustion process of biomass and sewage sludge," *J. Therm. Anal. Calorim.*, vol. 114, no. 2, pp. 519–529, 2013.

[12] L. Deng, T. Zhang, and D. Che, "Effect of water washing on fuel properties, pyrolysis and combustion characteristics, and ash fusibility of biomass," *Fuel Process. Technol.*, vol. 106, no. 0, pp. 712–720, Feb. 2013.
[13] S. Y. Luo, B. Xiao, Z. Q. Hu, S. M. Liu, and Y. W. Guan, "Experimental study on oxygen-enriched combustion of biomass micro fuel," *Energy*, vol. 34, no. 11, pp. 1880–1884, Nov. 2009.
[14] K. Slopiecka, P. Bartocci, and F. Fantozzi, "Thermogravimetric analysis and kinetic study of poplar wood pyrolysis," *Appl. Energy*, vol. 97, no. 0, pp. 491–497, Sep. 2012.
[15] J. Yu, C. Yao, X. Zeng, S. Geng, L. Dong, Y. Wang, S. Gao, and G. Xu, "Biomass pyrolysis in a micro-fluidized bed reactor: Characterization and kinetics," *Chem. Eng. J.*, vol. 168, no. 2, pp. 839–847, Apr. 2011.
[16] A. González, M. Penedo, E. Mauris, M. J. Fernández-Berridi, L. Irusta, and J. Iruin, "Pyrolysis analysis of different Cuban natural fibres by TGA and GC/FTIR," *Biomass and Bioenergy*, vol. 34, no. 11, pp. 1573–1577, Nov. 2010.
[17] W. de Jong, A. Pirone, and M. A. Wójtowicz, "Pyrolysis of Miscanthus Giganteus and wood pellets: TG-FTIR analysis and reaction kinetics☆," *Fuel*, vol. 82, no. 9, pp. 1139–1147, Jun. 2003.
[18] M. Nilsson, Å. Ingemarsson, J. R. Pedersen, and J. O. Olsson, "Slow pyrolysis of birch (Betula) studied with GC/MS and GC/FTIR/FID," *Chemosphere*, vol. 38, no. 7, pp. 1469–1479, Mar. 1999.
[19] L. Supeng, B. Guirong, W. Hua, L. Fashe, and L. Yizhe, "TG-DSC-FTIR Analysis of Cyanobacteria Pyrolysis," *Phys. Procedia*, vol. 33, no. 0, pp. 657–662, 2012.
[20] R. Bassilakis, R. M. Carangelo, and M. A. Wójtowicz, "TG-FTIR analysis of biomass pyrolysis," *Fuel*, vol. 80, no. 12, pp. 1765– 1786, Oct. 2001.
[21] W. de Jong, G. Di Nola, B. C. H. Venneker, H. Spliethoff, and M. A. Wójtowicz, "TG-FTIR pyrolysis of coal and secondary biomass fuels: Determination of pyrolysis kinetic parameters for main species and NOx precursors," *Fuel*, vol. 86, no. 15, pp. 2367–2376, Oct. 2007.
[22] Y. G. Pan, E. Velo, and L. Puigjaner, "Pyrolysis of blends of biomass with poor coals," *Fuel*, vol. 75, no. 4, pp. 412–418, Mar. 1996.
[23] M. J. Wornat, R. H. Hurt, N. Y. C. Yang, and T. J. Headley, "Structural and compositional transformations of biomass chars during combustion," *Combust. Flame*, vol. 100, no. 1–2, pp. 131–143, Jan. 1995.
[24] BritishStandardInstitute, "BS EN 14774-2:2009: Solid biofuels – Determination of moisture content – oven dry method. Part 2: Total moisture – simplified method," BS EN 14774-2:20092009.
[25] EU, "Decision support system for the application of renewable energy from biogas and biomass combustion under particular consideration of framework conditions in Vietnam and Thailand," Germany, 2005.
[26] S. Zafar, "Palm kernel shells as biomass resource," 2013. [Online]. Available: http://www.bioenergyconsult.com/tag/palm-oil-biomass/.
[27] I. M. Dagwa, P. F. Builders, and J. Achebo, "Characterization of palm kernel shell powder for use in polymer matrix composites," *Int. J. Mech. Mechatronics Eng.*, vol. 12, no. 04, pp. 88–93, 2012.
[28] M. Helin, "Moisture in wood fuels and drying of wood chips." North Karelia Polyteching, 2005.
[29] S. V. Loo and J. Koopejan, *The handbook of biomass combustion and co-firing*, 2nd ed. London: Earthscan, 2008, p. 4.
[30] J. K. Gigler, W. K. P. van Loon, M. M. Vissers, and G. P. A. Bot, "Forced convective drying of willow chips," *Biomass and Bioenergy*, vol. 19, no. 4, pp. 259–270, Oct. 2000.
[31] R. Jirjis, "Storage and drying of wood fuel," *Biomass and Bioenergy*, vol. 9, no. 1–5, pp. 181–190, 1995.
[32] C. Fyhr and A. Rasmuson, "Some aspects of the modelling of wood chips drying in superheated steam," *Int. J. Heat Mass Transf.*, vol. 40, no. 12, pp. 2825–2842, Aug. 1997.
[33] A. P. Schniewind, *Concise encyclopedia of wood & wood-based materials (Advances in materials sciences and engineering)*. New York: Pergamon, 1989, pp. 271–273.
[34] J. A. Pazó, E. Granada, Á. Saavedra, P. Eguía, and J. Collazo, "Uncertainty determination methodology, sampling maps generation and trend studies with biomass thermogravimetric analysis," *Int. J. Mol. Sci.*, vol. 11, no. 10, 2010.
[35] S. Mahanim, I. Asma, and J. Rafidah, "Production of activated carbon from industrial bamboo wastes.," *J. Trop. For. Sci.*, vol. 23, no. 4, pp. 417–424, 2011.
[36] G. Zheng and J. A. Koziński, "Thermal events occurring during the combustion of biomass residue," *Fuel*, vol. 79, no. 2, pp. 181–192, Jan. 2000.