UNIVERSITI PUTRA MALAYSIA

EMPTY FRUIT BUNCHES-DERIVED BIOCHAR FROM MICROWAVE-ASSISTED PYROLYSIS AS POTENTIAL RENEWABLE SOLID FUEL FOR POWER GENERATION

‘ATIYYAH AMEENAH BINTI AZNI

FK 2020 54

EMPTY FRUIT BUNCHES-DERIVED BIOCHAR FROM MICROWAVE-ASSISTED PYROLYSIS AS POTENTIAL RENEWABLE SOLID FUEL FOR POWER GENERATION

By

'ATIYYAH AMEENAH BINTI AZNI

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

September 2020

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

EMPTY FRUIT BUNCHES-DERIVED BIOCHAR FROM MICROWAVE-ASSISTED PYROLYSIS AS POTENTIAL RENEWABLE SOLID FUEL FOR POWER GENERATION

By

'ATIYYAH AMEENAH BINTI AZNI

September 2020

Chairman : Wan Azlina Binti Wan Ab Karim Ghani, PhD
Faculty : Engineering

The concerns on global climate change highlighted the need for renewable energy (RE) sources. Limited studies have been reporting on the utilization of Empty Fruit Bunch (EFB)-derived biochar (EFBC) as potential solid fuel for power generation. Microwave-assisted pyrolysis with susceptor has proven to be more efficient and economical for biomass conversion method. However, the technical risks and process efficiency on scale up microwave pyrolysis have not yet been fully assessed on demonstration plants.

Therefore, this research aims to select the best conditions of bench scale microwave pyrolysis of EFB in the presence of alumina susceptor and further assess the process performance of the best conditions from the bench scale in upscaled conditions. Besides, this research intends to evaluate the feasibility of EFBC as solid fuel for power generation.

Different pyrolysis temperatures between 200-400 °C as well as different feedstocks namely EFB pellet (PEFB) and EFB short fiber (FEFB) were used in a laboratory scale microwave pyrolyser (14 L), while the best conditions from the laboratory scale was applied in a 26x ratio upscaled microwave pilot pyrolyser (369 L). Further, FEFB-derived biochar (FEFBC) produced from the upscaled study and Blended (90% coal: 10% FEFBC) were compared against Sub-bituminous coal (SBC) via combustion tests using a 150 kW pilot combustor. Accordingly, analyses were done for both scale studies on pyrolysis performance, product yield and properties, as well as energy efficiency. Moreover, fuel characterization and combustion characteristics analyses were assessed for FEFBC, Blended and SBC according to the coal standard.

The results showed that temperature of 300 °C demonstrated the most ideal impact on the manufacture of biochar as well as residence time. EFB fiber achieved 62.5% faster process, 5.2% higher biochar yield and exhibited better biochar properties as compared to EFB pellet. Nevertheless, the process performance and biochar yield in the upscaled microwave pyrolysis have deteriorated, but apparently improved 58.3% of the energy output-input (EOI) ratio. Meanwhile, Blended sample has satisfied all standard coal parameters compared to FEFBC. Seemingly, Blended combustion generated 84% avoidance emission of nitric oxide (NO) gas than the SBC, though it increased the undesired ash slagging and fouling depositions.

In conclusion, the 26x ratio upscaled condition has given better EOI, and thus it is feasible to produce FEFBC at large scale via microwave pyrolysis. This study also suggests that addition of FEFBC in coal has the potential to be renewable solid fuel in power generation and reduce greenhouse gas (GHG) emissions.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

BIOCHAR TANDAN KOSONG KELAPA SAWIT DARIPADA PIROLISIS BERBANTU GELOMBANG MIKRO SEBAGAI POTENSI BAHAN API PEPEJAL BOLEH DIPERBAHARUI BAGI PENJANAAN KUASA

Oleh

'ATIYYAH AMEENAH BINTI AZNI

September 2020

Pengerusi : Wan Azlina Binti Wan Ab Karim Ghani, PhD
Fakulti : Kejuruteraan

Kebimbangan terhadap perubahan iklim global telah mendesak akan keperluan sumber tenaga boleh diperbaharui. Beberapa kajian terhad melaporkan *EFBC*, *biochar* daripada tandan kosong kelapa sawit *(EFB*) berpotensi sebagai bahan api pepejal untuk penjanaan tenaga. Pirolisis berbantu gelombang mikro dengan suseptor telah terbukti lebih cekap dan jimat bagi kaedah penukaran biojisim. Namun, risiko teknikal dan kecekapan proses ini belum dinilai sepenuhnya pada skala demonstrasi.

Oleh itu, kajian ini bertujuan menentukan kondisi terbaik dalam pirolisis gelombang mikro skala makmal ke atas *EFB* dengan kehadiran suseptor alumina dan selanjutnya menilai prestasi proses kondisi terbaik tersebut dalam skala lebih besar. Kajian ini juga bertujuan menilai kesesuaian *EFBC* sebagai bahan api pepejal untuk penjanaan kuasa.

Suhu pirolisis berbeza antara 200-400 °C dan stok suapan iaitu pelet *EFB (PEFB)* dan gentian pendek *EFB (FEFB)* digunakan dalam alatan pirolisis gelombang mikro skala makmal (14 L), manakala proses kondisi terbaik daripada skala makmal diaplikasikan dalam alatan pirolisis gelombang mikro skala 26x lebih besar (369 L). Selanjutnya, *biochar* daripada *FEFB (FEFBC)* terhasil dari kajian skala besar dan *Blended* (90% arang batu: 10% *FEFBC*) dibandingkan dengan arang batu Sub-bitumen *(SBC*) melalui ujian pembakaran dalam pembakar perintis 150 kW. Analisis dilakukan pada kedua-dua skala ke atas prestasi pirolisis, pengeluaran dan pencirian produk, dan juga kecekapan tenaga. Selain itu, analisis pencirian bahan api dan ciri-ciri pembakaran dinilai ke atas *EFBC*, *Blended* dan *SBC* berdasarkan piawai arang batu.

Keputusan menunjukkan bahawa suhu 300 °C memberikan kesan paling ideal ke atas pembuatan *biochar* dan tempoh proses. *FEFB* mencapai kadar proses 62.5% lebih pantas, penghasilan *biochar* 5.2% lebih banyak dan ciri-ciri *biochar* yang lebih baik berbanding *PEFB*. Namun demikian, prestasi proses dan penghasilan *biochar* daripada pirolisis gelombang mikro skala besar telah merosot, akan tetapi nisbah *output-input* tenaga *(EOI)* meningkat sebanyak 58.3%. Sementara itu, *Blended* memenuhi semua parameter piawai berbanding *FEFBC*. Ternyata, pembakaran *Blended* mengelakkan 84% pelepasan gas nitrik oksida *(NO)* berbanding *SBC*, walaupun pemendapan debunya meningkat.

Sebagai kesimpulan, *FEFBC* sesuai dihasilkan pada skala 26x lebih besar melalui pirolisis gelombang mikro berdasarkan *EOI* yang lebih tinggi. Selain itu, dicadangkan arang batu bercampur *FEFBC* berpotensi menjadi bahan bakar boleh diperbaharui bagi penjanaan kuasa dan pengurangan gas rumah hijau *(GHG)*.

ACKNOWLEDGEMENTS

First and foremost, all praise to Allah s.w.t. for His blessings and mercy that made all things possible. The completion of this thesis would certainly not have been possible without the help and support from few important persons and organizations.

I would first like to thank my supervisor, Prof. Ir. Dr. Wan Azlina Wan Ab Karim Ghani for giving me good guidelines for this research throughout numerous consultations. She constantly steered me on the right track whenever she thought I needed it. I would also like to acknowledge Assoc. Prof. Dr. Mohamad Amran Salleh and Assoc. Prof. Dr. Mohamad Fakri Zaky Ja'afar as the co-supervisors, and I am gratefully indebted to their very valuable comments on this work.

I would also like to express thanks to the personnel from Pakar Go Green Sdn Bhd who were involved in the operation of the microwave carbonizer system for this research: Mr. Aimi Zulfadli, Mr. Khairi Azlan and Ms Nurshahira. Without their participation, the microwave pyrolysis tests could not have been successfully conducted. A very special gratitude goes out to TNB Research Sdn Bhd for providing facilities on fuel combustion test and lab characterization.

I am also grateful to be supported by UPM's funding for this work: Geran Putra GPPI/2017/9558100 and Geran Putra GP-IPS/2018/9607200. Thanks also to the following university staff: Dr. Nor Shafizah, Ms Norhasliza and Mr. Adli Nazri for their kind assistance and technical support who have supported me along the way.

My very profound gratitude goes out to my father, Azni Idris and my mother, Rahana Mat Ghani for providing me with never-ending support, encouragement and understanding throughout my years of study and through the process of researching and writing this thesis. I am grateful to my other family members and friends who have helped me through moral and emotional support in my life. This achievement would not have been possible without them. To my dearest son, Mohammad Adly Ilman, "Mama owes you much!"

And finally, I would also like to expand my appreciation to all those who have indirectly involved in this study and in the process of completion of this thesis.
Thank you.

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

Wan Azlina Binti Wan Ab Karim Ghani, PhD
Professor, Ir.
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Mohamad Amran Bin Mohd Salleh, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Mohamad Fakri Zaky Bin Ja'afar, PhD
Associate Professor
Faculty of Design and Architecture
Universiti Putra Malaysia
(Member)

ZALILAH MOHD SHARIFF, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 12 November 2020

Declaration by graduate student

I hereby confirm that:

- this thesis is my original work;
- quotations, illustrations and citations have been duly referenced;
- this thesis has not been submitted previously or concurrently for any other degree at any other institutions;
- intellectual property from the thesis and copyright of thesis are fully-owned by Universiti Putra Malaysia, as according to the Universiti Putra Malaysia (Research) Rules 2012;
- written permission must be obtained from supervisor and the office of Deputy Vice-Chancellor (Research and Innovation) before thesis is published (in the form of written, printed or in electronic form) including books, journals, modules, proceedings, popular writings, seminar papers, manuscripts, posters, reports, lecture notes, learning modules or any other materials as stated in the Universiti Putra Malaysia (Research) Rules 2012;
- there is no plagiarism or data falsification/fabrication in the thesis, and scholarly integrity is upheld as according to the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) and the Universiti Putra Malaysia (Research) Rules 2012. The thesis has undergone plagiarism detection software.

Signature: _____ Date: _____

Name and Matric No.: 'Atiyyah Ameenah binti Azni, GS48496

Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) are adhered to.

Signature: _____
Name of Chairman of Supervisory Committee: Prof. Ir. Dr. Wan Azlina binti Wan Ab Karim Ghani

Signature: _____
Name of Member of Supervisory Committee: Assoc. Prof. Dr. Mohamad Amran bin Mohd Salleh

Signature: _____
Name of Member of Supervisory Committee: Assoc. Prof. Dr. Mohamad Fakri Zaky Bin Ja'afar

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATIONS

AC/DC	Alternating current/direct current
AFT(s)	Ash Fusion Temperature(s)
A/F	Air to fuel ratio
AI	Alkali index
Al_2O_3	Aluminum oxide
BaO	Barium oxide
Blended	Coal-biochar blend
C	Carbon
CaO	Calcium oxide
CH_3CHO	Acetaldehyde
CH_4	Methane gas
C_2H_2	Acetylene gas
Cl	Chlorine
CO	Carbon monoxide gas
CO_2	Carbon dioxide gas
EA	Activation energy
EE	Energy efficiency
EFB	Empty fruit bunch
EFBC	EFB-derived biochar
EOI	Energy output-input
ER	Equivalent ratio
EU	European Union
FEFB	EFB short fiber
FEFBC	EFB short fiber-derived biochar
Fe_2O_3	Ferric oxide
GHG	Greenhouse gas
HNO_3	Nitric acid
H_2SO_4	Sulfuric acid
H	Hydrogen
H_2	Hydrogen gas
HHV	Higher heating value
hr(s)	Hour(s)
IEA	International Energy Agency
K	Potassium
K_2O	Potassium oxide
LHV	Low heating value
LPG	Liquid petroleum gas
MBC	Magnetic biochar composite
MgO	Magnesium oxide
Mn_3O_4	Manganese oxide
MPOB	Malaysian Palm Oil Board
N	Nitrogen
N_2	Nitrogen gas
Na	Sodium
Na_2O	Sodium oxide
Nm^3	Normal meter cube
Nos	Numbers

NO	Nitric oxide gas
NO_2	Nitrogen dioxide gas
NO_x	Nitrogen oxide gas
O	Oxygen
O_2	Oxygen gas
OPF	Oil palm frond
OPMF	Oil palm mesocarp fiber
OPS	Oil palm shell
OPT	Oil palm trunk
P	Phosphorus
PAH(s)	Polycyclic aromatic hydrocarbon(s)
PEFB	EFB pellet
PEFBC	EFB pellet-derived biochar
P_2O_5	Phosphorus pentoxide
$R_{B/A}$	Base to acid ratio
RE	Renewable energy
SBC	Sub-bituminous coal
S	Sulfur
SDG(s)	Sustainable Development Goal(s)
SiC	Silicon carbide
SiO_2	Silicon dioxide
SO_3	Sulfur trioxide
TiO	Titanium oxide
TNBR	Tenaga Nasional Berhad (TNB) Research Sdn Bhd

CHAPTER 1

INTRODUCTION

1.1 Overview of coal as the primary source of energy

The concerns on global climate change and global warming have gained significant attention and highlighted the need for alternative energy sources (Onorevoli et al., 2018; Teh et al., 2017). The high consumption of fossil fuels results in the emission of GHG with carbon dioxide (CO_2) emission from coal combustion was the highest (43%) (Huang et al., 2017). Malaysia has devoted to reduce its carbon emissions up to 45% by 2030 by utilizing biomass as renewable energy (RE) (Energy Commission of Malaysia, 2018). In view of the challenges in hand, agro wastes and biomass could be explored further such as converting biomass into biochar in order to diversify the fuel mix.

1.2 Overview of biomass utilization for biochar source

Oil palm biomass waste has gained attention as a potential source for biochar production (Liew et al., 2017). Biochar refers to the carbon-rich residues, fine-grained, porous substance which has been recognized as a low-cost and multifunctional material (Bardalai and Mahanta, 2018; Wang et al., 2018). According to MPOB in 2016 (as cited in Mohamad Azri et al., 2018), palm oil industry in Malaysia generated more than 18.88 million tonnes of biomass which consist of empty fruit bunch (EFB), oil palm shell (OPS) and mesocorp fibers. Some of the biomasses are utilized as fuel for the boilers in the palm oil mills. Otherwise, the abundant unused and leftover biomasses are disposed to the landfills (Lam et al., 2017). In short, the abundant oil palm biomass leads to waste crisis and environmental issues. However, numerous studies have demonstrated the advantages of converting biomass into biochar. Among the advantages of biochar that is the focus of the study is that it is a promising sustainable source as solid fuel. This study investigates such potential.

1.3 Background study of biochar as solid fuel

The rapid increase in biomass production, the limited landfill sites as well as the great potential of biomass as a source of RE have stimulated the interest in converting the waste materials into biochar as solid fuels (Mubarak et al., 2016). Wan Azlina et al. (2014) proposed the applicability of sawdust-derived wood biochar as a solid fuel due to its high carbon content and calorific value characteristics. Additionally, Xing et al. (2017) suggested that the thermal properties of biochars derived from several forestry biomass are suitable for direct fuel applications, as reflected by their high energy density, high fixed carbon and lower ash contents. Xiangpeng and Hongwei (2011) also suggested the acceptable emission characteristics from combustion of Mallee biomass-derived biochar as a fuel in direct combustion or co-firing applications. However, biochar production by conventional method reflects lower quality than that of by

microwave heating method. Microwave pyrolysis seemingly produce better biochar properties which are 13.9% higher carbon content, 39.7% higher fixed carbon content and 15.2% higher calorific value as compared to biochar produced by the conventional pyrolysis (Fatimatul Zaharah and Farid Nasir, 2014). Therefore, microwave pyrolysis was the focus in this study.

1.4 Overview of microwave pyrolysis

There have been many microwave pyrolysis studies at laboratory level focusing on processing oil palm biomass such as EFB (Guan et al., 2018; Liew et al., 2017; Noor Afiqah, 2017; Shahril, 2017), OPS (Yek et al., 2019; Kong et al., 2018; Liew et al., 2017), oil palm trunk (OPT) (Liew et al., 2017; Hanisom et al., 2016) and oil palm frond (OPF) (Liew et al., 2017). Microwave pyrolysis has offered a better alternative to the conventional convection heating for pyrolysis of biomass because of its efficiency and time by ten times (90%). In the microwave heating, electromagnetic energy was converted into molecular kinetic energy. It induced heat at the molecular level and transferred heat from the inside to the surface of biomass by irradiation (Mubarak et al., 2016).

Particle size of the material sample is one of the concerns in the processing of biomass. Zhou et al. (2013) found out the effect of particle size during microwave pyrolysis of switchgrass was insignificant. At the same level of pyrolysis temperature of 600°C, the particle size of 0.5 - 4.0 mm of switchgrasses pyrolysed at similar residence time (13 min). Rather, Robinson et al. (2010) demonstrated that the effect of dielectric properties and power density were more significant in microwave pyrolysis of wood pellet. It was found that wood pellet had a threshold power density of 5.0×10^8 W/m^3 as the dielectric properties of the wood were at high temperatures (> 600 °C), below which the pyrolysis did not occur in wood but only in water. However, the effect of particle size on residence time was not reported. Mokhtar et al. (2012) also suggested that microwave heating dependent on the penetration depth of the material. During the energy absorption inside the material, the electric field would diminish when the distance increases from the surface to the inner of the material. Similarly, there was no available data on the effect of particle size of EFB pellet used in Rozita et al. (2011) study as the investigation was focus on the dielectric properties' characterization.

Several pilot studies on microwave heating method have emerged since 2009 such as a continuous chemical flatbed reactor heated with microwaves at capacity of 1250 L/hr using 480 kW (BFT Bionic Fuel Technologies AG, 2009), and a continuous microwave pyrolysis plant at capacity of 1250 tonnes/year (50 kW) and 1900 tonnes/year (75 kW) (Advanced Environmental Technologies Limited, 2019). However, no detail information on the plant operation and comprehensive energy analysis were reported to verify the economically viable process. Therefore, the technological transfer of microwave method to commercial scale is still indefinite.

Although the development of microwave pyrolysis plants has been tremendously advancing, maintenance issues continue to be a challenge. Shahril (2017) in his study demonstrated the difference of microwave susceptor materials in conjunction with

biochar yield and heating rate. Microwave pyrolysis on EFB fiber using three types of cylindrical susceptor vessels namely quartz, alumina and perlite with alumina vessel shown the best biochar yield. However, the fragility of perlite material has caused handling problem, while quartz required regular slags cleaning, thus contributing to high operational cost. Therefore, a low-cost reaction generated from a suitable susceptor should further be investigated.

1.5 Problem statement

Microwave pyrolysis with the presence of susceptor was suggested to be more efficient (Madhuchhanda and Tanmay, 2016). However, different susceptors have their own limitations in terms of the ability of energy absorption, abrasion resistance, fragility and slagging (Shahril, 2017). With limited studies, the low-cost susceptor is yet to find. Additionally, EFB fiber was reported to possess good carbon content after it has been pyrolysed in the presence of alumina (Shahril, 2017). Somehow the biochar properties from EFB fiber could not be generalized as the full characteristics have not been studied. In fact, the performance of other raw materials such as EFB pellet has not been investigated with the susceptor. Zhou et al. (2013) proposed the insignificant role of material particle size in microwave pyrolysis, rather, Robinson et al. (2010) emphasized on the power density pronounced more impact. However, this process was only for the switchgrass and wood pellet whereas no data reported for the EFB pellet. Besides, the challenge to scale up microwave pyrolysis has always been the technical risks which have not yet been fully assessed and mitigated on demonstration plants, hence preventing successful scale-up due to a shortage of data (Beneroso et al., 2017). It has been generally accepted that microwave pyrolysis provides energy saving with higher heating efficiency (Noraini et al., 2016; Koo et al., 2015), nevertheless this applies to the bench scale apparatus only. In terms of biochar as potential coal fuel, limited studies have been reporting on the utilization of EFB-derived biochar as solid fuel for power generation. For instance, Mubarak et al. (2016) developed magnetic biochar composite (MBC) derived from EFB as a potential coal fuel using microwave pyrolysis. However, no detail on the performance of the MBC was reported.

Recognizing the probable handling and maintenance issues may arise from inappropriate susceptors, hence the low-cost susceptor which is less maintenance issue such as alumina susceptor is crucial. Furthermore, the sample's particle size might also influence the heating efficiency of microwave pyrolysis. Thus, the different particle sizes such as pellet and fiber need to be compared. To ensure the successful scale-up and process efficiency, further pilot studies to validate the microwave heating efficiency are necessity. Although EFB biochar has been suggested as the potential solid fuel, the full analysis of the biochar in accordance with coal properties shall be studied. In view of the big shortage in this field of knowledge, this study was conducted.

1.6 Research objectives

The research objectives are outlined as below:

1. To select the best conditions of bench scale microwave pyrolysis of EFB (temperature and feedstock size).
2. To assess the up-scaled microwave pyrolysis performance of EFB at the best conditions from bench scale performance as basis.
3. To evaluate the feasibility of biochar as potential solid fuel for power generation in accordance with coal standard.

1.7 Scopes of study

The research scopes involve the following items:

1. Microwave pyrolysis performance of laboratory scale (14 L) on different pyrolysis temperatures (200, 270, 300, 350 and 400 °C) and feedstocks (EFB pellet and EFB short fiber), yield analysis, energy output-input ratio, as well as pyrolysis products characterization which include physico-chemical properties of EFBC, and compositions of bio-oil and syngas.
2. Microwave pyrolysis performance of pilot scale (369 L) at 300 °C on EFB short fiber, yield analysis, energy output-input ratio, as well as pyrolysis products characterization which include physico-chemical properties of the EFBC and compositions of bio-oil and syngas.
3. Coal test standard which include physico-chemical properties of EFBC, coal-biochar (90%:10%) blend and sub-bituminous coal (SBC).
4. Combustion test (150 kW), emission as well as ash deposition analyses of EFBC, coal-biochar blend and SBC.

1.8 Importance and significance

The innovation of microwave system equipped with alumina susceptor might promote a high-tech based solution for future industrial application in the thermal treatment area. The energy of the microwave pyrolysis especially using immense power, couples with the engineering scale-up issues demanding more beta testing to determine the process stability and economics are viable. Thus, this study will contribute to additional knowledge of microwave pilot study to the industries. This finding also serves as a first step towards qualifying biochar either from pure or blended types for application and meeting the requirement as solid fuel in coal-fired power plant.

In terms of research limitations, the preliminary study only tested at one pyrolysis temperature (300 °C) on EFB short fiber and the analysis for biomass properties was provided by the supplier (Usaha Strategik Sdn Bhd). The fuel characterizations and combustion test were done by the third party (TNB Research Sdn Bhd) to ensure the analyses were comparable with coal standard close to the full-scale conditions.

REFERENCES

Abdullah, N., Sulaiman, F., Gerhauser, H. 2011. Characterisation of Oil Palm Empty Fruit Bunches for Fuel Application. *Journal of Physical Science* 22: 1-24.

Adam, M., Katrib, J., Robinson, J., Kingman, S. 2015. Developing a Microwave Fluidised Bed Process for Biomass Pyrolysis. *15th International Conference on Microwave and High Frequency Heating (AMPERE 2015)*, AMPERE, Krakow.

Adeniyi, O.D., Idemudia G.E., Usman A.A., Adeniyi, M.I, Paul S.H., Olutoye, M.A., Dim P.E., Ngene P. 2018. Electrical Power Generation from Direct Carbon Duel Fuel Using Biochar from Eucalyptus, Neem and Mast Leaves. *International Journal of Scientific & Engineering Research* 9: 406-410.

Advanced Environmental Technologies Limited, 2019, Biomass Pyrolysis Plant for Bamboo or Wood with Microwave Technology, http://www.envcare.net/microwave-bamboo-pyrolysis-equipment.html (accessed 4 September 2019).

Alfredsson, M.S. Master Thesis. Effects of Different Fuels on Combustion Boiler Processes. KTH Royal Institute of Technology, 2018.

Analytical Fuel and Combustion Testing of a Co-firing Coal with Biochar; TNB Research Sdn Bhd (TNBR): Selangor, Malaysia, 2018.

Applicability. Guideline for the Installation and Maintenance of Continuous Emission Monitoring Systems (CEMS) for Industrial Premises/ Facilities, pp 4-6; Department of Environment Malaysia (DOE): Malaysia, 2009.

Asiatic Group (Holdings) Limited, 2020, Maju Intan Biomass Power Plant, https://asiatic.com.sg/our-businesses/energy/maju-intan-biomass-power-plant.html (accessed 22 September 2020).

Aziz, Nur Shahidah, A., Mohd Adib, M.N., Shareena Fairuz, A.M., Fazlena, H. 2015. Suitability of Biochar Produced from Biomass Waste as Soil Amendment. *Procedia - Social and Behavioral Sciences* 195: 2457-2465.

Azizan, M.T., Yusup, S., Mohd Laziz, F.D., Ahmad, M.M. 2009. Production of Bio-oil from Oil Palm's Empty Fruit Bunch via Pyrolysis. *Proc. 3rd WSEAS Int. Conf. Renew. Energy Sources*, pp 228-233.

Barbanera, M., Cotana F., Di Matteo, U. 2018. Co-Combustion Performance and Kinetic Study of Solid Digestate with Gasification Biochar. *Renewable Energy* 121: 597-605.

Bardalai, M., Mahanta, D.K. 2018. Characterisation of Biochar Produced by Pyrolysis from Areca catechu Dust. *Materials Today: Proceedings* 5: 2089-2097.

Beneroso, D., Monti, T., Kostas, E.T., Robinson, J. 2017. Microwave Pyrolysis of Biomass for Bio-Oil Production: Scalable Processing Concepts. *Chemical Engineering Journal* 316: 481-498.

Bhatta K., Bhawana, C.A., Brodie, G. 2018. Biochar from Biosolids Microwaved-Pyrolysis: Characteristics and Potential for Use as Growing Media Amendment. *Journal of Analytical and Applied Pyrolysis* 130: 249-255.

Biomass Co-firing - An Efficient Way to Reduce Greenhouse Gas Emissions; European Bioenergy Networks (EUBIONET): Finland, 2003.

Bionic Microfuel; Microwave Depolymerisation (MWDP); Procedural Facility for the 2nd Generation Production of Synthetic Fuels from Biomass and Waste; BFT Bionic Fuel Technologies AG: Gross-Gerau, Germany, 2009.

Blue Palm Biofuel Sdn Bhd, 2020, Specialists in Modern Biomass Fuel Production: Shinmoji Biomass Power Plant (100MW), https://bluepalmbiofuel.com (accessed 22 September 2020).

Buratti, C., Barbanera, M., Bartocci, P., Fantozzi, F. 2015. Thermogravimetric Analysis of the Behavior of Sub-bituminous 7 Coal and Cellulosic Ethanol Residue During Cocombustion. *Bioresource Technology* 186: 154-162.

Chen, D.,Yu, X., Song, C., Pang, X., Huang, J., Li, Y. 2016. Effect of Pyrolysis Temperature on the Chemical Oxidation Stability of Bamboo Biochar. *Bioresource Technology* 218: 1303-1306.

Chunfei, W., Budarin, V.L., Gronnow, M.J., De Bruyn, M., Onwudili, J.A., Clark, J.H., Williams, P.T. 2014. Conventional and Microwave-Assisted Pyrolysis of Biomass Under Different Heating Rates. *Journal of Analytical and Applied Pyrolysis* 107: 276-283.

Chungen, Y. 2012. Microwave-assisted Pyrolysis of Biomass for Liquid Biofuels Production. *Bioresource Technology* 120: 273-284.

Coal specifications. Contract Specification for Manjung Power Station, TNB Janamanjung Sdn Bhd (500017): Appendix E & I; TNB Research Sdn Bhd (TNBR): Malaysia, 2016.

Contreras, M.L., Garcı´a-Frutos, F.J., Bahillo, A. 2015. Study of the Thermal Behaviour of Coal/Biomass Blends During Oxy-Fuel Combustion By Thermogravimetric Analysis. *Journal of Thermal Analysis and Calorimetry* 123: 1643-1655.

Dai, X., Wu, C., Li, H., Chen, Y. 2000. The Fast Pyrolysis of Biomass in CFB Reactor. *Energy and Fuels* 14: 552–557.

De, M. Azargohar, R., Dalai, A.K., Shewchuk, S.R. 2013. Mercury Removal by Bio-Char Based Modified Activated Carbons. *Fuel* 103: 570-578.

Di Gianfrancesco, A. The fossil fuel power plants technology. In Materials for Ultra-Supercritical and Advanced Ultra-Supercritical Power Plants; 2017; Elsevier Ltd: Amsterdem, Netherlands, pp 1-49.

Dunnigan, L., Ashman, P.J., Zhang, X., Kwong, C.W. 2018. Production of Biochar from Rice Husk: Particulate Emissions from the Combustion of Raw Pyrolysis Volatiles. *Journal of Cleaner Production* 172: 1639-1645.

Faisal, M., Ramli, M., Farid Nasir, A. 2014. A Review on Microwave Assisted Pyrolysis of Coal and Biomass for Fuel Production. *Renewable and Sustainable Energy Reviews* 39: 555-574.

Faisal, M., Tuan Amran, T.A., Ramli, M., Farid Nasir, A. 2015. Optimization and Characterization of Bio-Oil Produced by Microwave Assisted Pyrolysis of Oil Palm Shell Waste Biomass with Microwave Absorber. *Bioresource Technology* 190: 442-450.

Fatimatul Zaharah, A., Farid Nasir, A. 2014. Comparing Characteristics of Oil Palm Biochar Using Conventional and Microwave Heating. *Jurnal Teknologi (Sciences & Engineering)* 68: 33-37.

Gholizadeh, M., Hu, X., Liu, Q. 2019. A Mini Review of the Specialties of the Bio-Oils Produced from Pyrolysis of 20 Different Biomasses. *Renewable and Sustainable Energy Reviews* 114:109-313.

Guan, S.H., Hasan, M.F. and Farid Nasir, A. 2018. Microwave Induced Pyrolysis of Oil Palm Biomass by Using Layer Microwave Absorber in Reverse Flow Double Cylinder Reactor. *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 46: 129-138.

Guda, V.K., Steele, P.H., Penmetsa, V.K., Li, Q. 2015. Fast Pyrolysis of Biomass. *Recent Advances in Thermo-Chemical Conversion of Biomass* 177-211.

Hachenberg, N. PhD Thesis. Predictions of NOx Emissions in Pulverized Coal Combustion. University of Louisville, 2014.

Hanisom, A., Jie, W.S., Norjan, Y., Illyas, M.I. 2016. Fuel and Ash Properties of Biochar Produced from Microwave-Assisted Carbonisation of Oil Palm Trunk Core. *Journal of Oil Palm Research* 28: 81-92.

Harsono, S.S., Grundman, P., Lau, L.H., Hansen, A., Mohammad Amran, M.S., Meyer-Aurich, A., Azni, I., Tinia Idaty, M.G. 2013. Energy Balances, Greenhouse Gas Emissions and Economics of Biochar Production from Palm Oil Empty Fruit Bunches. *Resources, Conservation and Recycling* 77: 108-115.

He, X., Liu, Z., Niu, W., Yang, L., Zhou, T., Qin, D., Niu, Z., Yuan, Q. 2018. Effects of Pyrolysis Temperature on The Physicochemical Properties of Gas and Biochar Obtained from Pyrolysis of Crop Residues. *Energy* 143: 746-756.

Huang, Y-F., Chiueh, P-T., Shih, C-H., Lo, S-L., Sun, L., Zhong, Y., Qiu, C. 2015. Microwave Pyrolysis of Rice Straw to Produce Biochar as an Adsorbent for CO_2 capture. *Energy* 84: 75-82.

Huang, Y-F., Cheng, P-H., Chiueh, P-T., Lo, S-L. 2017. Leucaena Biochar Produced by Microwave Torrefaction: Fuel Properties and Energy Efficiency. *Applied Energy* 204: 1018-1025.

Huang, Y-F., Kuan, W-H., Chang, C-Y. 2018. Effects of Particle Size, Pretreatment, and Catalysis on Microwave Pyrolysis of Corn Stover. *Energy* 143: 696-703.

Jameel, H., Keshwani, D., Carter, S., Treasure, T. 2010. Thermochemical Conversion of Biomass to Power and Fuels. *Biomass to Renewable Energy Processes, Cheng, J*. (ed): 447-487.

Kabir, G., Mohd Din, A.T., Hameed, B.H. 2017. Pyrolysis of Oil Palm Mesocarp Fiber and Palm Frond in a Slow-heating Fixed-bed Reactor: A Comparative Study. *Bioresource Technology* 241: 563-572.

Khlewee, M.M. Master Thesis. Production of Bio-oil with Different Oxygen Content and Characterization of Catalytic Upgrading to Transportation Fuel. University of Maine, 2017.

Kiarie - Makara, M.W., Yoon, H.S., Lee, D.K. 2010. Repellent Efficacy of Wood Vinegar Against *Culex pipiens pallens* and *Aedes togoi* (Diptera: Culicidae) Under Laboratory and Semi - Field Conditions. *Entomological Research* 40: 97-103.

Kiky C.S., Nino, R., Sabar, P.S. 2015. Bio-oil from Fast Pyrolysis of Empty Fruit Bunch at Various Temperature. *Energy Procedia* 65:162-169.

Kong, S-H., Lam, S.S., Yek, P.N.Y., Liew, R.K., Ma, N.L., Mohammad Shahril, O., Wong, C.C. 2018. Self-Purging Microwave Pyrolysis: An Innovative Approach to Convert Oil Palm Shell into Carbon-Rich Biochar for Methylene Blue Adsorption. *Journal of Chemical Technology & Biotechnology* 94: 1397-1405.

Koo, W.K., Gani, N.A., Shamsuddin, M.S., Subki, N.S., Sulaiman, M.A. 2015. Comparison of Wastewater Treatment using Activated Carbon from Bamboo and Oil Palm: An Overview. *Journal of Tropical Resources and Sustainable Science* 3: 54-60.

Królczyk, J.B., Rezwiakow, A., Tukiendorf, M. 2014. Mixing of Biomass and Coal in a Static Mixer as an Example of Technological Solutions Involving Implementation of Renewable Energy Sources. *Ecological Chemistry and Engineering Science* 21: 685-696.

Kyoto Protocol; United Nations Framework Convention on Climate Change (UNFCCC): Germany, 2014.

Lam, S.S., Wan Adibah, W.M., Wan Mahari, Jusoh, A.., Chong, C.T., Lee, C.L., Chase, H.A. 2017. Pyrolysis Using Microwave Absorbents as Reaction Bed: An Improved Approach to Transform Used Frying Oil into Biofuel Product with Desirable Properties. *Journal of Cleaner Production* 147: 263-272.

Liew, R.K., Nam, W.L., Chong, M.Y., Phang, X.Y., Su, M.H., Yek, P.N.Y., Ma, N.L., Cheng, C.K., Chong, C.T., Lam, S.S. 2017. Oil Palm Waste: An Abundant and Promising Feedstock for Microwave Pyrolysis Conversion into Good Quality Biochar with Potential Multi-Applications. *Process Safety and Environmental Protection* 5: 57-69.

Liew, R.K., Chai, C., Yek, P.N.Y., Phang, X.Y., Chong, M.Y., Nam, W.L., Su, M.H., Lam, W.H., Ma, N.L., Lam, S.S. 2019. Innovative Production of Highly Porous Carbon for Industrial Effluent Remediation Via Microwave Vacuum Pyrolysis Plus Sodium-Potassium Hydroxide Mixture Activation. *Journal of Cleaner Production* 208: 1436-1445.

Lourencon, T.V., Mattos, B.D., Cademartori, P.H.G., Magalhães, W.L.E. 2016. Bio-oil from a Fast Pyrolysis Pilot Plant as Antifungal and Hydrophobic Agent for Wood Preservation. *Journal of Analytical and Applied Pyrolysis* 122: 1-6.

Madhuchhanda, B., Tanmay, B. 2016. A Review On the Susceptor Assisted Microwave Processing of Materials. *Energy* 97: 306-338.

Mattos, C., Veloso, M.C.C., Romeiro, G.A., Folly, E. 2019. Biocidal Applications Trends of Bio-Oils from Pyrolysis: Characterization of Several Conditions and Biomass, A Review. *Journal of Analytical and Applied Pyrolysis* 139: 1-12.

Menezes, R.R, Souto, P.M., Kiminami, R.H.G.A. 2007. Microwave Hybrid Fast Syntering of Porcelain Bodies. *Journal of Materials Processing Technology* 190: 223-229.

Mohamad Azri, S., Chin, M.A., Nor Kartini, A.B. 2009. Bio-oils from Pyrolysis of Oil Palm Empty Fruit Bunches. *American Journal of Applied Sciences*, 6: 869-875.

Mohamad Azri, S., Loh, S.K., Abu Bakar, N. 2018. Conversion of Pre-treated Oil Palm Empty Fruit Bunches into Bio-oil and Biochar via Fast Pyrolysis. *Journal of Oil Palm Research* 30: 121-129.

Mohammadshirazi, A., Akram, A., Rafiee, S., Bagheri Kalhor, E. 2014. Energy and Cost Analyses of Biodiesel Production from Waste Cooking Oil. *Renewable and Sustainable Energy Reviews* 33: 44-49.

Mohammed, I.Y., Abakr, Y.A., Hui, J.N.X., Alaba, P.A., Morris, K.I., Ibrahim, M.D. 2017. Recovery of Clean Energy Precursors from Bambara Groundnut Waste via Pyrolysis: Kinetics, Products Distribution and Optimisation Using Response Surface Methodology. *Journal of Cleaner Production* 164: 1430-1445.

Mohd Qaharuddin, A. Master Thesis. Trial Burn Firing of New C Coal at Kapar Energy Ventures (KEV) Power Station, Malaysia. Universiti Putra Malaysia, 2012.

Mook, T.L., Ahmad, R., Chen, S.D., Noor Akma Watie, M.N., Azmi, A., Hamdan, H., Mohd Hariffin, B., Lou, C. 2015. Preliminary Determination of Flame Speeds from Infrared Images Using Image Processing Techniques in a 150 Kwth Coal-Fired Combustion Test Rig. *International Journal of Advancements in Mechanical and Aeronautical Engineering* 2: 140-144.

Motasemi, F., Afzal, M.T. 2013. A Review on the Microwave-Assisted Pyrolysis Technique. *Renewable and Sustainable Energy Reviews* 28: 317-330.

Motasemi, F., Salema, A.A., Afzal, M.T. 2015. Dielectric Characterization of Corn Stover for Microwave Processing Technology. *Fuel Processing Technology* 131: 370-375.

Mubarak, N.M., Sahu, J.N., Abdullah, E.C., Jayakumar, N.S. 2016. Plam Oil Empty Fruit Bunch Based Magnetic Biochar Composite Comparison for Synthesis by Microwave-Assisted and Conventional Heating. *Journal of Analytical and Applied Pyrolysis* 120: 521-528.

Noor Afiqah, M. PhD Thesis. Conventional and Microwave Pyrolysis of Empty Fruit Bunch and Rice Husk Pellets. University of Sheffield, 2017.

Noraini, M.N., Abdullah, E.C., Othman, R., Mubarak, N.M. 2016. Single-Route Synthesis of Magnetic Biochar from Sugarcane Bagasse by Microwave-Assisted Pyrolysis. *Materials Letters* 184: 315-319.

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.

Onorevoli, B., Da Silva Maciel, G.P., Machado, M.E., Corbelini, V., Caramão, E.B., Jacquesa, R.A. 2018. Characterization of Feedstock and Biochar from Energetic Tobacco Seed Waste Pyrolysis and Potential Application of Biochar as an Adsorbent. *Journal of Environmental Chemical Engineering* 6: 1279-1287.

Onsree, T., Tippayawong, N., Zheng, A., Li, H. 2018. Pyrolysis Behavior and Kinetics of Corn Residue Pellets And Eucalyptus Wood Chips in a Macro Thermogravimetric Analyzer. *Case Studies in Thermal Engineering* 12: 546-556.

Ozbay, G., Ayrilmis, N. 2017. Effect of Pyrolysis Temperature on Bio-Oil Production from Vacuum Pyrolysis of Waste from Wood Industry. *International Journal of Advances in Science Engineering and Technology* 5: 60-62.

Özçimen, D., Ersoy-Meriçboyu, A. 2010. Characterization of Biochar and Bio-Oil Samples Obtained from Carbonization of Various Biomass Materials. *Renewable Energy* 35: 1319-1324.

Papari, S., Hawboldt, K. 2015. A Review on the Pyrolysis of Woody Biomass to Bio-oil: Focus on Kinetic Models. *Renewable and Sustainable Energy Reviews* 52: 1580-1595.

Park, H.Y., Park, Y.H., Kim, Y.J., Kim, H.H., Park, S.B. 2017. The Interaction of Woody Biomass with Bituminous Coal in Their Blends. *Environmental Engineering Research* 22: 320-328.

Rangabhashiyam, S., Anu, N., Selvaraju, N. 2013. Sequestration of Dye from Textile Industry Wastewater using Agricultural Waste Products as Adsorbents. *Journal of Environmental Chemical Engineering* 1: 629-641.

Renewable Energy (RE). Annual Report 2014, pp 34-44; Sustainable Energy Development Authority Malaysia (SEDA): Malaysia, 2014.

Robinson, J.P., Kingman, S.W., Barranco, R., Snape, C.E., Al-Sayegh, H. 2010. Microwave Pyrolysis of Wood Pellets. *Ind Eng Chem Res* 49: 459-463.

Ruksathamcharoen, S., Chuenyam, T., Stratong-on, P., Hosoda, H., Sesillia, T., Yoshikawa, K. 2019. Effects of Hydrothermal Treatment and Pelletizing Temperature on Physical Properties of Empty Fruit Bunch Pellets. *Energy Procedia* 158: 681-687.

Roos, C. 2010. Clean Heat and Power Using Biomass Gasification for Industrial and Agricultural Projects, pp 1-9; Department of Energy: U.S., 2010.

Rozita, O., Idris, A., Yunus, R., Khalid, K., Aida Isma, M.I. 2011. Characterization of Empty Fruit Bunch for Microwave-assisted Pyrolysis. *Fuel* 90: 1536-1544.

Sahu, S.G., Sarkar, P., Chakraborty, N., Adak, A.K. 2010. Thermogravimetric Assessment of Combustion Characteristics of Blends of a Coal with Different Biomass Chars. *Fuel Processing Technology* 91: 369-378.

Sarkar, P., Sahu, S.G., Chakraborty, N., Adak, A.K. 2014. Studies on Potential Utilization of Rice Husk Char in Blend with Lignite for Cocombustion Application. *Journal of Thermal Analysis and Calorimetry* 115: 1573–1581.

Sarkar, P., Sahu, S.G., Mukherjee, A., Kumar, M., Adak, A.K., Chakraborty, N., Biswas, S. 2014. Co-combustion Studies for Potential Application of Sawdust or Its Low Temperature Char as Co-Fuel with Coal. *Applied Thermal Engineering* 63: 616-623.

Shahril, S. Master Thesis. Pyrolysis of EFB by Using Microwave Radiation with Different Cylindrical Reactor Chamber. Universiti Putra Malaysia, 2017.

Siu, H.C. 2018. Bio-oil Derived from Palm Empty Fruit Bunches: Fast Pyrolysis, Liquefaction and Future Prospects. *Biomass and Bioenergy* 119: 263-276.

Suman, S., Gautam, S. Biochar Derived from Agricultural Waste Biomass Act as a Clean and Alternative Energy Source of Fossil Fuel Inputs; 2018. IntechOpen Limited: London, United Kingdom.

Teh, Y.Y., Lee, K.T., Chen, W-H., Lin, S-C., Sheen, H-K., Tan, I.S. 2017. Dilute Sulfuric Acid Hydrolysis of Red Macroalgae *Eucheuma denticulatum* with Microwave-Assisted Heating for Biochar Production and Sugar Recovery. *Bioresource Technology* 246: 20-27.

The Role of Bioenergy in Europe after COP 21 Paris. Declaration of Graz; Bioenergy Europe: Brussels, Belgium, 2017.

The Transition. Energy Malaysia, vol. 14, 2018, pp 6-43; Energy Commission of Malaysia (ST): Malaysia, 2018.

Tripathi, M., Sahu, J.N., Ganesan, P. 2016. Effect of Process Parameters on Production of Biochar from Biomass Waste through Pyrolysis: A Review. *Renewable and Sustainable Energy Reviews* 55: 467-481.

Upgrading the Efficiency of the World's Coal Fleet to Reduce CO_2 Emissions. Cornerstone, 3:1, pp 4-9; Clean Coal Centre: France, 2012.

Vargas, E., Pantoya, M.L., Saed, M.A., Weeks, B.L. 2016. Advanced Susceptors for Microwave Heating of Energetic Materials. *Materials & Design* 90: 47-53.

Vieira, F.R., Luna, C.M.R., Arce, G.L.A.F., Ávila, I. 2020. Optimization of Slow Pyrolysis Process Parameters Using a Fixed Bed Reactor for Biochar Yield from Rice Husk. *Biomass and Bioenergy* 132: 105412.

Wan Azlina, W.A.K.G., Da Silva, G., Azil, B.A. 2014. Physico-Chemical Characterizations of Sawdust-Derived Biochar as Potential Solid Fuels. *The Malaysian Journal of Analytical Sciences* 18: 724-729.

Wan, Y., Chen, P., Zhang, B., Yang, C., Liu, Y., Lin, X. 2009. MicrowaveAssisted Pyrolysis of Biomass: Catalysts to Improve Product Selectivity. *Journal of Analytical and Applied Pyrolysis* 86: 161-167.

Wang, H., Wang, X., Cui, Y., Xue, Z., Ba, Y. 2018. Bioresource Technology Slow Pyrolysis Polygeneration of Bamboo (*Phyllostachys pubescens*): Product Yield Prediction and Biochar Formation Mechanism. *Bioresource Technology* 263: 444-449.

Wang, P., Maliang, H., Wang, C., Ma, J. 2015. Bamboo Charcoal By-products as Sources of New Insecticide and Acaricide. *Industrial Crops and Products* 77: 575-581.

Weixiang, W., Song, D., He, X., Liu, X., Li, Z., Tian, X. 2019. The Heterogeneity and Electro-Mechanical Characteristics of Coal at the Micro- and Nanoscale. *Journal of Geophysics and Engineering* 16: 717-728.

Wu, K., Park, H.S., Willert-Porada, M. 2012. Pyrolysis of Polyurethane by Microwave Hybrid Heating for the Processing of NiCr Foams. *Journal of Materials Processing Technology* 212: 1481-1487.

Xiangpeng, G., Hongwei, W. 2011. Biochar as a Fuel: 4. Emission Behavior and Characteristics of PM1 and PM10 from the Combustion of Pulverized Biochar in a Drop-Tube Furnace. *Energy Fuels* 25: 2702-2710.

Xing, Y., Wang, H., Strong, P.J., Xu, S., Liu, S., Lu, K., Sheng, K., Guo, J., Che, L., He, L., Ok, Y.S., Yuan, G., Shen, Y., Chen, X. 2017. Thermal Properties of Biochars Derived from Waste Biomass Generated by Agricultural and Forestry Sectors. *Energies* 10: 469.

Yek, P.N.Y. 2019. Microwave Steam Activation, an Innovative Pyrolysis Approach to Convert Waste Palm Shell nto Highly Microporous Activated Carbon. *Journal of Environmental Management* 236: 245-253.

Yousaf, B., Liu, G., Abbas, Q., Wang, R., Ali, M.U., Ullah, H., Liu, R., Zhou, C. 2017. Systematic Investigation on Combustion Characteristics and Emission Reduction Mechanism of Potentially Toxic Elements in Biomass and Biochar Coal Co-Combustion Systems. *Applied Energy* 208: 142-157.

Zhao, B., Connor, D.O., Zhang, J., Peng, T., Shen, Z., Tsang, D.C.W., Hou, D. 2018. Effect of Pyrolysis Temperature, Heating Rate, and Residence Time on Rapeseed Stem Derived Biochar. *Journal of Cleaner Production* 174: 977–87.

Zhao, C., Vleugels, J., Groffils, C., Luypaert, P.J., Van der Biest, O. 2000. Hybrid Sintering with a Tubular Susceptor in a Cylindrical Single Mode Microwave Furnace. *Acta Materialia* 48: 3795-3801.

Zhou, R., Lei, H., Julson, J.L. 2013. Effects of Reaction Temperature, Time and Particle Size on Switchgrass Microwave Pyrolysis and Reaction Kinetics. *International Journal of Agricultural and Biological Engineering* 6: 53-61.

Zhu, L., Lei, H., Wang, L., Yadavalli, G., Zhang, X., Wei, Y., Liu, Y., Yan, D., Chen, S., Ahring, B. 2015. Biochar of Corn Stover: Microwave-Assisted Pyrolysis Condition Induced Changes in Surface Functional Groups and Characteristics. *Journal of Analytical and Applied Pyrolysis* 115: 149-156.