UNIVERSITI PUTRA MALAYSIA

OIL PALM EMPTY FRUIT BUNCH CARBONIZATION IN PILOT SCALE AND INDUSTRIAL SCALE HORIZONTAL ROTARY DRUMS

LAU LEK HANG

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By

LAU LEK HANG

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

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Chairman : Mohamad Amran b. Mohd Salleh, PhD
Faculty : Engineering

Oil palm empty fruit bunch, EFB, is one of the biomass wastes generated from the palm oil production industry. Currently most of the EFB are incinerated or utilized as the boiler fuels for steam and electricity generation, some are mulched or composted naturally in the plantation; however these processes generally aggravated environmental problems due to process inefficiency. EFB conversion to biochar is a promising way to resolve the EFB disposal issue, as it is a renewable energy and a carbon neutral cycle if to be used as fuel, contributing in mitigating climate change. The objective of this study is to obtain optimum carbonization conditions of EFB in a horizontal rotary drum towards the char yield and properties. Carbonization conditions to be included are final carbonization temperature and retention time of carbonization.

EFB was characterized in laboratory of its elementary composition and moisture content by using CHNS/O-932 analyser and themogravimetry analyser. The results were comparable with previous works. Laboratory thermogravimetry analysis of EFB at 10^{o}C/min, 30^{o}C/min and 50^{o}C/min heating rates using TGA analyser has shown that the maximum decomposition temperatures at different heating rates were in the range of 360^{o}C to 370^{o}C, suggesting good char yield with reasonable preserved calorific values could be produced at carbonization temperature above 370^{o}C. EFB was then carbonized in pilot rotary horizontal drum reactor developed by Nasmech Technology Sdn Bhd at 400^{o}C, 500^{o}C and 600^{o}C with 2.5 hours, 3.0 hours and 3.5 hours retention times and char products from different batch of tests were tested for proximate analysis and calorific values. The EFB char yields are in the range of 21.8% to 26.4%, increase with lower carbonization temperature but no significant effect with retention time. Both carbonization temperature and retention time have no significant effect on calorific value of chars which were at the range of 21.50 MJ/kg to 23.98 MJ/kg. The higher carbonization temperature reduced volatile content and increasing fixed carbon content of char. Retention time has no significant effect towards the char proximate composition

EFB char carbonization in 20 T/Day industrial scale rotary drum reactor, developed by Nasmech Technology Sdn Bhd has been performed at 350^{o}C and 400^{o}C final

carbonization temperature at 5 hours retention time. The analysis on char product have shown the EFB char produced possessed 22.71 MJ/kJ average calorific value for 400^{o}C char, similar quality with pilot scale char product at same 400^{o}C condition but higher char calorific value of 24.43 MJ/kg was produced at 350^{o}C. This concludes that the char quality is greatly affected by final carbonization temperature and not much by retention time under isotherm final carbonization temperature condition. Yield of Dengkil plant are at average of 22.23% for 400^{o}C char and 25.12% for 350^{o}C char. Dengkil char is classified as medium quality fuel in the rank of bituminous or subbituminous equivalent quality according to ASTM D388 standard classification method for coal,

Specific carbonization energy of EFB and heat transfer flux rate through feedstock contact area with reactor drum surface could be used as preliminary scale up criteria of horizontal rotary drum. However the accuracy of upscale rules could be enhanced with further study and incorporation of others heat transfer parameters.

Several operational hiccups have been reported for the Dengkil plant for future improvement and to minimize operational downtime of similar reactor system. Despite those shortfalls, the economics and energy balance of EFB char carbonization plant in Dengkil has also been studied by others and concluded that this plant is technical feasible and economically viable with net energy yield of EFB char produced at 11.47 MJ/kg EFB. From this study, optimum EFB char yield and quality is best produced at 350^{o}C to 400^{o}C with 5 hours retention time in the industrial scale horizontal rotary drum carbonization reactor.

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

KARBONISASI TANDAN BUAH KOSONG KELAPA SAWIT DALAM DRUM BERPUTAR MELINTANG SCALA LOJI PILOT DAN SCALA LOJI INDUSTRI

Oleh

LAU LEK HANG

Januari 2016

Pengerusi : Mohamad Amran b. Mohd Salleh, PhD
Fakulti : Kejuruteraan

Tandan buah kosong kelapa sawit, *EFB*, adalah salah satu daripada sisa biojisim yang dijanakan daripada industri pengeluaran minyak sawit. Pada masa kini sebahagian daripada *EFB* adalah dibakar atau digunakan sebagai bahan api dalam dandang dan untuk penjanaan stim dan elektrik, manakala sebahagiannya diluputkan secara semula jadi dalam ladang kelapa sawit. Walau bagaimanapun proses-proses ini dipercayai akan mendatangkan kesan buruk kepada alam sekitar yang disebabkan oleh ketidakcekapan proses. Penukaran *EFB* kepada arang asas tumbuhan, atau *biochar,* adalah penyelesaian yang berpotensi untuk menyelesaikan isu pelupusan *EFB*, kerana *EFB* adalah jenis tenaga yang boleh diperbaharui dan mematuhi kitaran karbon neutral jika digunakan sebagai bahan api, menyumbang dalam mengurangkan impak-impak perubahan iklim. Objektif kajian ini adalah untuk mendapatkan keadaan optimum untuk karbonisasi *EFB* dalam *drum* putaran mendatar dengan mengkaji kesan keadaan karbonisasi terhadap hasil ciri-ciri arang. Keadaan-keadaan karbonisasi proses yang dikaji termasuklah suhu akhir proses karbonisasi dan masa pengekalan bahan-bahan *EFB* dalam karbonisasi proses atau *retention time*.

EFB diuji dalam makmal komposisi untuk sifat-sifat fisikal dan kandungan kelembapan dengan menggunakan alat penganalisis CHNS/O-932 dan penganalisis *themogravimetry (TGA)*. Keputusan analisis didapati mempunyai persamaam dengan kajian sebelum ini. Analisis *termogravimetry EFB* telah dijalankan pada kadar pemanasan 10^{o}C/min, 30^{o}C/min dan 50^{o}C/min dengan menggunakan *TGA* menunjukkan bahawa suhu penguraian maksimum pada kadar pemanasan yang berbeza adalah dalam julat 360^{o}C hingga 370^{o}C, mencadangkan suhu karbonisasi haruslah lebih tinggi dari julat suhu tersbut untuk mendapatkan kadar penghasilan produk yang baik lagi memelihara nilai kalori arang *EFB*. *EFB* kemudian dikarbonisasikan dalam reaktor berputar melintang direka dan dipasangkan oleh Nasmech Teknologi Sdn Bhd pada suhu 400^{o}C, 500^{o}C dan 600^{o}C dengan 2.5 jam, 3.0 jam dan 3.5 jam *retention time* dan produk arang dari kumpulan ujian yang berbeza telah dianalisa untuk mendapatkan nilai kalori dan *proximate analysis* masing-masing. Kadar hasil arang *EFB* adalah dalam lingkungan 21.8% ke 26.4%, dengan kadar hasil meningkat apabila suhu

karbonisasi menurun tetapi tiada kesan yang ketara dari *retention time*. Kedua-dua suhu karbonisasi dan *retention time* tidak mempunyai kesan yang besar ke atas nilai kalori arang yang diuji yang didapati dalam lingkungan 21.50 MJ/kg hingga 23.98 MJ/kg. Suhu karbonisasi yang lebih tinggi megurangkan kandungan meruap atau *volatiles* dan menambahkan kandungan karbon tetap (*fixed carbon*) dalam arang *EFB*. Selain itu, *retention time* tidak mempunyai kesan yang ketara kepada komposisi *proximate analysi*s dalam arang *EFB*.

Karbonisasi *EFB* dalam reaktor berputar mlintang skala industri berkapasiti 20 ton sehari yang didirikan oleh Nasmech Teknologi Sdn Bhd di Dengkil telah dijalankan pada suhu karbonisasi akhir 350^{o}C dab 400^{o}C selama 5 jam. Keputusan analysis menunjukkan arang *EFB* yang dihasilkan mempunyai nilai kalori purata 22.71 MJ/kg untuk arang hasilan dari 400^{o}C, mempunyai kualiti yang setanding dengan produk aranng skala pilot, manakala nilai kalori purata yang lebih tinggi telah diperolehi pada 24.43 MJ/kg untuk arang hasilan 350^{o}C. Ini menyimpulkan bahawa kualiti arang yang sangat dipengaruhi oleh suhu karbonisasi akhir dan tidak banyak dipengaruhi oleh *retention time* di bawah keadaan suhu karbonisasi isoterma akhir. Kadar penghasilan arang pada keadaan 350^{o}C dan 400^{o}C dari Carbonator® Dengkil adalah 22,23% dan 25.12% secara puratanya. Arang *EFB* yang dihasilkan dari Carbonator® Dengkil juga diklasifikasikan sebagai arang bermutu serdanaha dalam kategori *bituminous* atau *subbituminous* dalam kaedah piawai ASTM D388 untuk pengelasan kualiti arang batu.

Tenaga karbonisasi spesifik *EFB* dan kadar pemindahan haba fluks melalui kawasan sentuhan bahan mentah dengan permukaan reaktor *drum* boleh digunakan sebagai kriteria kasar untuk peningkatskalaan reaktor karbonisasi *drum* putaran mendatar. Walau bagaimanapun ketepatan peraturan peningkatskalaan tersebut boleh diperincikan lagi dengan kajian lanjut dan pengambikiraan parameter pemindahan haba yang lain.

Beberapa rintangan operasi kilang Dengkil telah dilaporkan untuk penambahbaikan pada masa hadapan dan untuk mengurangkan masa penghentian (*downtime*) operasi untuk sistem reaktor yang sama. Walaupun dihadapi kekurangan, ekonomi dan tenaga baki karbonisasi proses untuk menghasilkan arang *EFB* di Dengkil telah juga dikaji oleh pengkaji lain dan menyimbulkan bahawa sistem karbonisasi ini boleh diusahakan dari segi kesesuaian teknikal dan berdaya maju dari segi ekonomi dengan hasil tenaga bersih arang *EFB* yang dihasilkan pada 11.47 MJ/kg *EFB.* Dari analysis kajian ini, kadar hasilan and kualiti arang *EFB* yang optimum dapat dihasilkan pada 350^{o}C – 400^{o}C dalam 5 jam di dalam *drum* karbonisasi mendatar industri.

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I certify that a Thesis Examination Committee has met on 28 January 2016 to conduct the final examination of Lau Lek Hang on his thesis entitled "Oil Palm Empty Fruit Bunch Carbonization in Pilot Scale and Industrial Scale Horizontal Rotary Drums" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

Members of the Thesis Examination Committee were as follows:

Salmiaton binti Ali, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Mohd Halim Shah bin Ismail, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Robert Thomas Bachmann, PhD
Senior Lecturer
University of Kuala Lumpur
Malaysia
(External Examiner)

ZULKARNAIN ZAINAL, PhD
Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 21 April 2016

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:

Mohamad Amran b. Mohd Salleh, PhD
Senior Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Azni b. Idris, PhD
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

BUJANG KIM HUAT, PhD
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School of Graduate Studies
Universiti Putra Malaysia

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Signature : ______________________
Name of Chairman of Supervisory Committee: Dr. Mohamad Amran b. Mohd Salleh

Signature: ______________________
Name of Member of Supervisory Committee: Professor Dr. Azni b. Idris

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a	Time of firing
Ase	Effective area of material accumulated in the rotating reactor in contact with the drum surface, m^2
b	Time (nearest to 0.1 min) when the temperature reaches 60% of the total rise
c	Time at beginning of period (after the temperature rise) in which the rate of temperature change has become constant
CV_{mmf}	Gross calorific value, moist metal-matters free, BTU/lb
D	Reactor drum diameter
D_1	Pilot Carbonator® reactor drum diameter, m
D_2	Dengkil 20 T/Day Carbonator® reactor drum diameter, m
DTG	Mass ratio reduction variation rate or derivative thermogravimetric
dT	Temperature difference between external reactor drum and bulk solids
e_3	Centimeters of fuse wire consumed in firing
FC_{mmf}	Fixed carbon content, moist, metal-matters free, %
H_g	Gross heat of combustion
L	Effective length of reactor drum
L_1	Pilot Carbonator® reactor drum effective length, m
L_2	Dengkil 20 T/Day Carbonator® reactor drum effective length, m
m	Mass of sample in grams
m_1	Mass of EFB per batch test in pilot EFB Carbonator®
m_2	Mass of EFB per batch test in Dengkil 20 T/Day Carbonator®
mmf	Moist, metal-matters free
q_1	Specific energy received by EFB for reaction throughout the total retention time in pilot Carbonator®

q_2	Specific energy received by EFB for reaction throughout the total retention time in Dengkil Carbonator®
Q	Effective heat transmitted to material in the reactor
Q_1	Heat transmitted effectively to the EFB in Carbonator® reactor for pilot Carbonator®
Q_2	Heat transmitted effectively to the EFB in reactor for Dengkil Carbonator®
r	Radius of rotating reactor drum
r_1	Rate (temperature units per minutes) at which the temperature was rising during the 5 min period before the firing
r_2	Rate (temperature unit per minute) at which the temperature was rising during the 5 minutes, period after time c.
t	Temperature rise
t_1	Retention time for pilot Carbonator® test at 2.5 hours
t_2	Retention time for Dengkil 20 T/Day Carbonator® test at 5 hours
t_a	Temperature at the time of firing
t_c	Temperature at time c
TGA	Thermogravimetric analysis
U	Overall heat transfer coefficient
V	Volume of material filling the bottom of reactor
VM_{mmf}	Volatile matter, moist metal-matters free, %
W	energy equivalent of the equivalent, determined under standardization

Greek Symbol

ρ_1	Bulk density of EFB charged into pilot Carbonator®
ρ_2	Bulk density of EFB charged into Dengkil 20 T/Day Carbonator®
θ	Angle of filling of material accumulated in horizontal rotating reactor

CHAPTER 1

INTRODUCTION

Oil palm was naturally originated from Africa and was first introduced for planting in the Botanical Gardens in Singapore in 1870 [1]. It has now become one of the major commodities contributing to Malaysian economic growth since 3 decades ago. The Malaysia total land area is amounts to 32.90 million hectares, and major agricultural crops grown in Malaysia are rubber (39.67%), oil palm (34.56%), rice (12.68%), cocoa (6.75%) and coconut (6.34%) [**1**]. With the sharp expansion of palm oil demand and production, palm oil waste (empty fruit bunch, fiber, shell, fronds and trunks) from palm oil production has increased tremendously. Malaysia as the top two largest palm oil producer in the world has generated more than 7 million tons of EFB, 4.5 million tons of fiber and 1.9 million tons of shell as solid waste at an increase of 5% annually [2], while empty fruit bunch, EFB generation has struck 17.08 million tons in year 2009 [3]. Currently most of the waste are incinerated or utilized as the boiler fuels for steam and electricity co-generation, some are mulched or composted naturally in the plantation; however these processes generally aggravated environmental problems due to process inefficiency [**2**].

1.1. Background of study

There have been many studies conducted to resolve agricultural waste in Malaysia recent years. Many of the studies have been conducted to explore the new ways to reuse these wastes as energy, fertilizer or even household furniture, while resolving the environment impact these waste would impose if left as they were. Oil palm empty fruit bunch, EFB, is particularly of interest as it was a rejected by product from the crude palm oil production process with potential energy content. There are a few attempted reuse applications of EFB including reused as fuel in the biomass boiler for palm oil mills [**4**], mulched as fertilizer and processed as pressed wood for furniture making.

EFB is a type biomass containing calories potentially to be used as fuel. However EFB in reality contain rather high moisture content at more than 55% [**5**], which is the key disadvantage quality as fuel. High moisture and the residue oil in the EFB left from the palm oil extraction process often accelerate the natural decaying process shortening EFB storage time. Charcoal is the blackish residue consisting of impure carbon obtained by removing water and other volatile constituents. Conversion of EFB into charcoal would enhance its potential values as fuel by increasing the burning quality with the removal of moisture and extending its storage period as well as preserving or to certain extend may densify its calorific energy.

Besides potential mass application as fuel in industrial co-generation process, biomass charcoal has been widely used in human society especially for cooking and heating. In Malaysia, mangrove wood charcoal is the most common charcoal used since decades ago. Biomass conversion into charcoal activities has also been practiced in human society since thousands of years ago. Conventional charcoal production method or technology is time consuming and labour intensive. The main mangrove wood charcoal production area in Malaysia is located in Perak state, along Matang Mangrove Forest Reserve focusing around Kuala Sepetang with conventional brick kiln technology which would take up to 30 days for one carbonization cycle in a kiln with about 10.5 tons per batch feed, or 90 kg/day of charcoal production rate assuming 25% yield.

1.2. Problem Statement

EFB is one of the agricultural wastes in Malaysia with increasing generation rate along with palm oil industry growth. Current EFB waste management methods through mulching in the oil palm plantation have been associated with potential greenhouse gases release into atmosphere especially when the anaerobic biodegradation of mulch occurs [**6**], and high operational cost due to increased labour and transportation cost as well as labour shortage [**6, 7, 8**]. Use of EFB as co-generation fuel is feasible yet imperfect with inconsistent combustion quality originated air pollution problem due to its high moisture content, while other EFB commercial applications are being explored and developed. Conversion of EFB into charcoal would enhance its burning quality. With modern technological evolvement and increasing market needs, biomass charcoal production technology with improved efficiency and production capacity are being developed but such studies for EFB were mainly limited at laboratory scale and some at pilot scale. There is lack of industrial scale carbonization process of EFB study reported hence the study on such scale of process is important for practical improvement and promotion of commercial sustainable EFB carbonization process. Rotary drum reactor is suitable for bulk carbonization processing of untreated EFB but with limited understandings of the effects of processing conditions towards char quality and yield especially at industrial capacity.

1.3. Objectives

A rotary drum carbonization system has been developed by Nasmech Technology Sdn Bhd for EFB conversion to char and this study is focusing in understanding the effect of some selected process parameters towards the EFB char quality produced from the pilot scale and industrial scale Carbonator® system. This is achieved through multiple objectives of studies as following :

1. To investigate the effect of heating rate on EFB decomposition characteristics and char yield.
2. To examine the effect of final carbonization temperature and retention time on EFB char yield and fuel properties for pilot and industrial scale horizontal rotary drum kiln.
3. To identify and verify the upscale criteria used for rotary drum kiln.
4. To establish the optimum operating conditions to produce a cost-effective EFB charcoal in a rotary horizontal kiln for fuel application

From previous research studies on EFB pyrolysis, higher char yield is promoted with lower heating rate, lower final carbonization temperature and longer residence time. Therefore it is projected that the similar trends and effects would be found in laboratory experiments as well as in the pilot and industrial scale horizontal rotary drum reactor with proper control of heat losses through the bigger equipment and process parameters. The upscale criteria is also expected to be identified with consistency of heat transfer and reactor sizing between pilot and industrial rotary drum in this study. The findings of this study will also be able to conclude optimum process conditions for this type of rotary drum carbonization reactor, with respect to the optimum calorific value and properties most suitably served as solid fuel.

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