PROPERTIES OF BIOCHAR PRODUCED FROM MICROWAVE-ASSISTED CARBONISATION OF OIL PALM TRUNK CORE

WUN SHUN JIE

05-4506832 pustaka.upsi.edu.my Perpustakaan Tuanku Bainun Kampus Sultan Abdul Jalil Shah PustakaTBainun ptbupsi

THESIS SUBMITTED IN FULFILLMENT OF THE REQUIREMENT FOR THE DEGREE OF MASTER OF SCIENCE (BIOLOGY) (MASTER BY RESEARCH)

FACULTY OF SCIENCE AND MATHEMATICS
SULTAN IDRIS EDUCATION UNIVERSITY

2015

05-4506832 pustaka.upsi.edu.my Perpustakaan Tuanku Bainun Kampus Sultan Abdul Jalil Shah PustakaTBainun ptbupsi

ABSTRACT

This research aimed to assess the properties of biochar fuel produced using microwave-assisted carbonisation of oil palm trunk core (OPTC) biomass. Microwave-assisted carbonisation of OPTC was investigated under several sizes, temperatures and microwave power variables. The fuel properties of raw OPTC and biochar products were characterised by physical and chemical analyses. An open-ended coaxial probe method was used to measure the effect of frequency, moisture content and structural direction towards dielectric properties of OPTC. The result showed that raw OPTC contained high moisture content (~64.3%), low fixed carbon (~6.4%) and low calorific value (0.0046 $GJkg^{-1}$). Dielectric constant of OPTC was found to decrease with the increasing of microwave frequency. Regardless of OPTC structural directions, an increasing pattern of dielectric constant and dielectric loss was detected with the increasing moisture content in biomass. The increasing of carbonisation temperatures resulted in decreased biochar yield. The optimum conditions which yielded 8.4% biochar was obtained at 350^oC, power 800W and 6 cm^3 OPTC size. In conclusion, OPTC can be classified as a medium absorbing biomass. Microwave-assisted carbonisation has produced biochar with four times higher calorific value than raw OPTC. The implication of this study is OPTC biochar has high slagging and fouling tendencies that could impose technical challenges in the future bioenergy applications.

CIRI-CIRI ARANG BIO YANG DIHASILKAN DARIPADA TERAS BATANG KELAPA SAWIT MELALUI KARBONISASI BERBANTUKAN GELOMBANG MIKRO

ABSTRAK

Kajian ini dijalankan bertujuan menilai ciri-ciri bahan api arang bio yang dihasilkan dari teras batang kelapa sawit (OPTC) melalui karbonisasi berbantukan gelombang mikro. Karbonisasi OPTC berbantukan gelombang mikro telah dikaji untuk pembolehubah-pembolehubah saiz biojisim, suhu dan kuasa gelombang mikro. Ciri-ciri tenaga OPTC mentah dan produk arang bio telah diuji menggunakan analisis fizikal dan kimia. Kaedah prob koaksial hujung-terbuka telah digunakan untuk mengukur kesan frekuensi, kandungan kelembapan dan arah struktur terhadap sifat dielektrik OPTC. Hasil kajian menunjukkan OPTC mentah mempunyai kelembapan tinggi (~64.3%), rendah karbon terikat (~6.4%) serta rendah nilai tenaga (0.0046 $GJkg^{-1}$). Pemalar dielektrik OPTC didapati menurun dengan peningkatan frekuensi gelombang mikro. Manakala, pemalar dielektrik dan faktor kerugian pula meningkat dengan peningkatan kandungan kelembapan bagi semua arah struktur OPTC. Hasil arang bio telah berkurang dengan peningkatan suhu karbonisasi. Keadaan suhu 350^{o}C, kuasa 800W dan saiz 6 cm^3 berjaya menghasilkan hasil optimum arang bio sebanyak 8.4%. Kesimpulan kajian menunjukkan, OPTC ialah biojisim penyerap gelombang mikro jenis sederhana. Produk arang bio yang dihasilkan mempunyai lebih empat kali ganda nilai tenaga berbanding OPTC mentah. Implikasi dari kajian ini ialah produk arang bio berpotensi tinggi untuk membentuk lapisan berkaca, mengkakis dinding reaktor serta boleh menyebabkan cabaran teknikal dalam aplikasi tenaga bio di masa depan.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 Background and motive

In the year 1870, oil palm tree *Elaeis guineensis* was introduced as an ornamental tree in Malaysia through Singapore Botanic Gardens. The first commercial planting of oil palm took place at Selangor in 1917 (Chin, 2011). Since then, the palm oil industry has grown rapidly throughout the years. It then became the fourth largest contributor to the Gross National Income (GNI) of Malaysia, accounting for approximately 8 percent or over RM 80 billion of GNI (Agensi Inovasi Malaysia, 2013).

In this industry, the main product is palm oil that is pressed from fresh fruit. There are two types of oils: palm oil and palm kernel oil. Palm oil is used in food products such as cooking oil, margarine and shortenings while palm kernel oil is used in nonfood products such as soaps, detergents, toiletries, cosmetics and candles (*Palm oil facts & figures*, 2013).

Malaysia has large oil palm plantation areas that reached 5.08 million hectares in December 2012 (Aljuboori, 2013). The areas constitute 77 percent of agricultural land or approximately 15 percent of total land area (*Palm oil facts & figures*, 2013). However, the palm oil industry only focuses on palm oil. In particular, six types of oil palm biomass are produced as by-products (wastes of palm oil industry), which are oil palm fronds (OPF), oil palm trunks (OPT), empty fruit bunches (EFB), palm kernel shells (PKS), mesocarp fibre (MF) and oil palm mill effluent (OPME) (Aljuboori, 2013). In 2012, the palm oil industry produced over 83 million dry tonnes of solid biomass waste from which 75 percent was found in plantation and 25 percent was generated in mills (Agensi Inovasi Malaysia, 2013). As one of the solid biomass wastes produced from plantation, OPT are generated every 25 to 30 years during oil palm tree replantation (Amouzgar, Khalil, Salamatinia, Abdullah & Issam, 2010). According to this life span, the rate of OPT generation was estimated to be 62.80 tonne-dry per hectare-replantation per year (Aljuboori, 2013).

With the abundance of OPT biomass resources, innovators in the wood industry have the incentive to use OPT as a material to produce plywoods, fibre boards and furniture (Agensi Inovasi Malaysia, 2013). However, most of the oil palm trunk cores (OPTC) that are not utilised in the wood industry are excluded as wastes in the end of the process (Loh, Tahir, & Yeoh, 2011). Hence, there is a need to accelerate technology development so that OPTC biomass wastes can be utilised to produce biofuels and bio-energy. Such advancement can facilitate the implementation of Renewable Energy Policy and Action Plan, which targets 4,000 megawatts of installed renewable energy capacity by 2030. This is an increase of 17 percent from the less than 1 percent of the total installed today (Agensi Inovasi Malaysia, 2013).

1.2 Problem statement

With a short productivity life span of about 25 years, oil palm trees are replanted every 25 to 30 years, and they produce abundant OPT biomass (Agensi Inovasi Malaysia, 2013; Amouzgar et al., 2010). The annual availability of oil palm trunks was estimated to be 13.6 million logs per 100,000 hectares as replanted every year (Amouzgar et al., 2010). The abundant OPT biomass used to be excluded and burnt in fields, creating environmental issues. Hence, this procedure was banned. Instead, the OPT biomass was left at the fields to decompose, and this process normally takes five years for complete degradation (Szymona, Cichy, Borysiuk, Paik, & Maminski, 2011).

At present, a small portion of OPT are utilised in the timber industry. Around 40 percent of OPT biomass is consumed in the production of medium density fibreboards, fibre-reinforced cement boards, fibre-plastic composites, plywoods, blockboards, laminated-veneer lumbers and furniture (Loh et al., 2011; Wan Asma, Mahanim, Zulkafli, Otman, & Mori, 2010). The consumption of the centre of OPT is limited by its morphology and weak mechanical performance because oil palm is monocotyledon without secondary thickening (Szymona et al., 2011).

During the processing of OPT for the production of timber products, the outer part of OPT is utilised for manufacturing timber products but much oil palm trunk core (OPTC) biomass is left as waste due to its weak mechanical performance (Loh et al., 2011). Some plywood factories also process OPTC waste into ruminant pellet for their own domestic farm but this practise is not widely commercialised.

Alternatively, this high sugar content OPTC biomass waste could be used in biochemical conversion to produce bio-ethanol as biofuel. However, this conversion shows some weaknesses or drawbacks such as its productivity is limited by the amount of bulky biomass relative to the size of reactor. In addition, the optimum condition for biochemical conversion have to keep on maintained throughout the whole process (Verma et al., 2012). Hence, the efficiency of converting OPTC into biofuel by biochemical conversion is low.

Other than biochemical route, OPTC can be converted into biofuel using the following conventional thermochemical applications; (1) it can be burnt in an uncontrolled condition for heat and electricity generation and (2) it can be served as a boiler fuel for electricity generation at oil palm mills. The direct utilisation of raw biomass as boiler fuels is challenging because the process suffers inefficient energy conversion and high fuel production cost (Trummer, 2004). Besides that, there are problems in utilising raw biomass for the substance is bulky, high in moisture, low in volumetric energy density, and low in terms of grindability due to its fibrous nature (Abdullah & Wu, 2009).

In summary, the problems arise from processing of bulky low economic value OPTC biomass highlighted the need of an innovative thermochemical conversion method so that raw OPTC can be efficiently converted into biofuels with enhanced properties for various applications in the future. In view of waste minimisation perspectives, the innovative method should allow fully utilisation of whole oil palm trunk. While the outer part of the biomass contributes to the wood industry, the core can be converted into biofuels.

1.3 Significance of research

In this study, the conversion of OPTC into biochar was investigated via thermochemical route using microwave-assisted carbonisation. Carbonisation is one of the thermochemical conversion methods used to increase the efficiency of energy conversion. The method is used to produce charcoal by heating the biomass in an almost or complete absence of air or oxygen (Ronsse, 2013; Yokoyama & Matsumura, 2008).

Conventionally, kiln is used to perform carbonisation. There are several disadvantages of kiln carbonisation, for instance, biomass is required to be dried and cut into smaller size before being subjected to carbonisation. Large energy is required during the drying and cutting process in order to produce dry biomass that can accelerate the carbonisation process (Yokoyama & Matsumura, 2008). Besides that, the process also takes a long carbonisation time. For example, with a low efficiency of about 10 to 20 percent, the earth kiln or metal kiln takes days or weeks for complete carbonisation (NL Agency, 2013).

Following the disadvantages of kiln carbonisation, new technologies are applied in the design of pyrolysis reactors to increase the product yield of carbonisation. However, these reactors are only suitable for granular materials and not for application on logged biomass. In the past 100 years, studies on the pyrolysis of large-sized biomass were scarce (Pelaez-Samaniego, Garcia-Perez, Cortez, Rosillo-Calle, & Mesa, 2008). Pyrolysis involves applying a heating method that transfers heat from heated kilns or reactors to biomass. However, this carbonisation method suffers several drawbacks including lack of rapid heating: its long heating duration triggers the undesired secondary reaction and produces low yield of the desired product (Abas & Ani, 2014).

Compared to conventional heating, microwave heating is able to perform carbonisation of biomass with numerous advantages including material selective, and offering non-contact, rapid and volumetric heating. The process provides a kind of

energy transfer instead of heat transfer, and heating begins from the center of the material towards its surface. In addition, microwave heating is easy to control; it can be operated and terminated quickly, and the safety and automation of the heating is high (Haque, 1999; Menéndez, Inguanzo, & Pis, 2002; Menéndez, Domínguez, Inguanzo, & Pis, 2005; Menéndez et al., 2010; Robinson, Kingman, Barranco, & Snape, 2010). One of the most fundamental properties of microwave energy application in the thermal degradation of biomass is being material-selective heating, which results in different microwave energy absorption for different biomass or biomass dielectric properties (Menéndez et al., 2010; Omar, Idris, Yunus, & Khalid, 2010). The application of microwave in thermochemical conversion became the focus of the present study because recent developments in microwave pyrolysis have achieved interesting and valuable results.

For example, microwave energy have successfully been employed to pyrolyse large-sized feedstock as reported previously (Miura, Kaga, Sakurai, Kakuchi, & Takahashi, 2004; Zhao et al., 2010). Past results have highlighted the potential application of microwave-assisted carbonisation for bulky OPTC, which is an underutilised biomass for power generation in Malaysia. Microwave irradiation had been employed to dry OPTC for lumber manufacturing (Amouzgar et al., 2010). Conclusively, the microwave-drying had reduced the drying time and had resulted in better removal of moisture compared to the results achieved from oven-drying.

From literature data, a key research gap has been identified that is the thermochemical conversion of bulky oil palm biomasses were rather limited. Hence, further studies and developments are needed to garner a better understanding of

microwave-assisted carbonisation of large size biomasses available in Malaysia. The efficiency of a microwave application process is largely influenced by the ability of microwave energy absorption (Salema et al., 2013), and the ability of microwave energy absorption is highly dependent on the biomass feedstock material and its conditions. Therefore, it is important to obtain the fundamental data of OPTC dielectric properties under various biomass conditions. In this research, the dielectric properties of OPTC were studied under the variables of frequency, moisture content and structural directions. The correlations would show the interaction between microwave field and OPTC biomass under various conditions. In previous studies, the dielectric properties of oil palm shell, oil palm fibre and empty fruit bunch were reported (Omar, Idris, Yunus, Khalid, & Isma, 2011; Salema et al., 2013). However, publications on the dielectric properties of OPTC are scarcely available in the existing literature. In view of optimizing OPTC waste utilisation in carbonisation, the biomass' dielectric properties need to be investigated.

Besides understanding the behavior of OPTC under microwave irradiation, deep understandings about fuel and ash properties of raw OPTC and its biochar products is crucial for future application in bioenergy sector. Previously, some fuel properties of selected oil palm biomasses such as EFB, OPS and OPF were reported but their ash properties were not well understood (Omar et al., 2011; Salema & Ani, 2012a). Hence, investigation about fuel and ash properties of OPTC is also significant.

In addition, this research focuses on evaluating the performance of OPTC carbonisation by using microwave irradiation. In the present study, microwave-

assisted carbonisation of OPTC was performed at low temperature (300^{o}C – 400^{o}C). This is because previous studies, which used conventional heat source at 300^{o}C to 400 ℃ to perform slow pyrolysis on Australian woody biomass, produced biochar with improved grindability and fuel properties that highly matched to those of Collie coal's (Abdullah & Wu, 2009). In the Malaysian context of biochar production from OPTC biomass, the carbonisation of OPTC and its biochar fuel properties has not been fully investigated, particularly the process within the low range of pyrolysis temperatures.

With the advantages of microwave heating, the interest of the present study is on the systematic examination of the carbonisation of OPTC biomass that are controlled under such low carbonisation temperatures, particularly by using microwave as heat source. Any improvement in OPTC biochar fuel properties will significantly be advantageous for energy densification, increasing combustion efficiency, reducing transportation cost, and enhancing fuel processing/handling. All these in turn, will open more opportunities for generating high quality biofuels from oil palm biomass. This helps to secure the Malaysian bioenergy production in the near future.

1.4 Research objectives

The objectives of this research are as follows:

1. To evaluate the fuel and ash properties of raw oil palm trunk core (OPTC) as comparison to selected oil palm biomasses.
2. To analyse the dielectric properties of an oil palm trunk core under various conditions.
3. To assess the carbonisation of the oil palm trunk core by a microwave-assisted process at low temperature and characterisation of biochar products

1.5 Thesis outline

There are six chapters in this thesis. As schematically illustrated in the thesis map (Figure 1.1), each chapter is organized as follows:

Chapter 1 introduces the research background, motives, problem statement, significance of research and research objectives.

Chapter 2 summarizes the literature review on biomass issues, oil palm industry in Malaysia, current thermochemical conversion technology, advantages of using microwave-assisted carbonisation, study of dielectric properties of biomass and slagging and fouling issues.

Chapter 3 presents the methodology on the analysis of properties of biofuels and carbonisation of OPTC.

Chapter 4 discusses the fuel and ash properties of oil palm biomasses and the dielectric properties of OPTC at various frequencies, moisture content and structural directions. Besides that, it also discusses the biochar yield at various sizes, temperatures and microwave powers. The properties of biochar is discussed in this chapter too.

Chapter 5 concludes this study and states recommendations for further study.

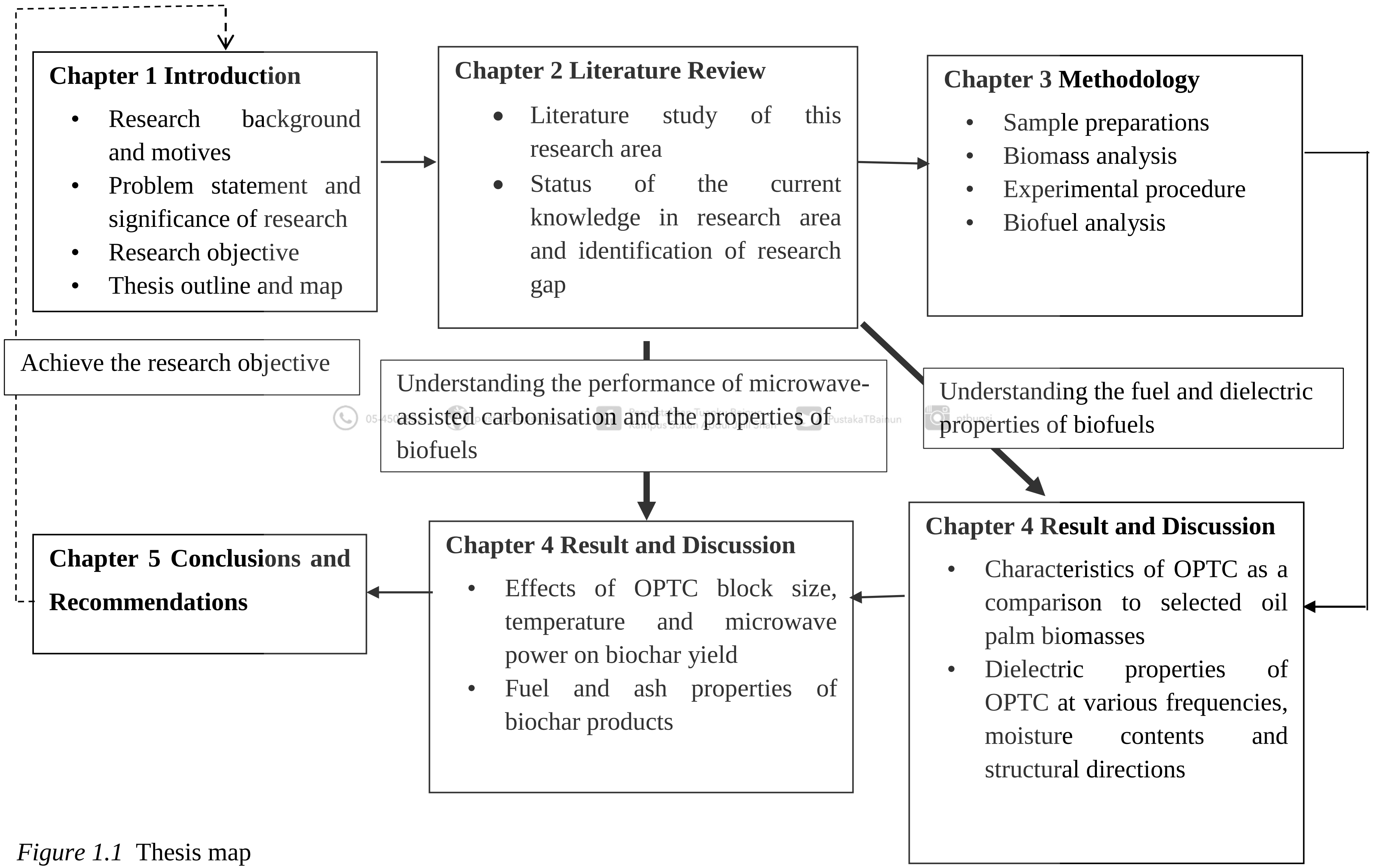

Figure 1.1 Thesis map

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter firstly provides a review on the oil palm industry in Malaysia as oil palm trunk core (OPTC) was the main biomass used in this research. In particular, the chapter discusses the availability of oil palm plantations in Malaysia, biomass generation from this industry, uses of oil palm biomass in the present applications and details on the structure of an oil palm trunk.

Then, this chapter discusses the thermochemical conversion technology especially the carbonisation technology. The potential of applying microwave in carbonisation biomass is evaluated and the up-to-date studies on microwave-assisted conversion of oil palm biomass are reviewed. Dielectric properties of biomass are also reviewed in this chapter to understand the interaction between biomass and microwave field. The fuel properties of biomass and biochar products are discussed to give an overview of the important factors affecting biofuels performance in power plant. Finally, the research gaps that lead to the significance of the present study are identified in the end of this chapter.

2.2 Biomass

Biomass is the organic material obtained from plants and animals; it can be used for creating useful energy in various forms and for diverse purposes (Mckendry, 2002; Ogwo, Dike, Mathew, & Akabuogu, 2012). The organic materials are produced by green plants through photosynthesis from which the energy of sunlight is stored in the chemical bonds of the organic materials. Chemical energy is released when the bonds between the adjacent carbon, hydrogen, and oxygen molecules are broken by digestion, combustion or decomposition (Mckendry, 2002). The chemical energy is extracted and classified as three categories: solid fuel, liquid biofuel and biogas (The Schumacher Centre, 2008).

2.2.1 Classification of biomass

Biomass can be classified according to their biological diversity, source and origin as showed in Table 2.1.