Faculty of Engineering

# PRODUCTION AND CHARACTERIZATION OF BIOCOAL FROM AGRICULTURAL BIOMASS USING MICROWAVE-INDUCED TORREFACTION

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Bachelor of Engineering with Honours
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**UNIVERSITI MALAYSIA SARAWAK**

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# PRODUCTION AND CHARACTERIZATION OF BIOCOAL FROM AGRICULTURAL BIOMASS USING MICROWAVE-INDUCED TORREFACTION

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A dissertation submitted in partial fulfillment
of the requirement for the degree of
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(Chemical Engineering)

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Dedicated to my beloved parents and friends, who always bestow me sustainable motivations and encouragements

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# ABSTRACT

The use of biomass energy can lower the effect of global warming from the existing fossil fuels-powered plants and reduce the release of toxic and carcinogenic emissions. In concern with the large quantity of agricultural waste being abundant and poorly disposed, the conversion of the waste into biocoal with a proper treatment may help to solve the waste disposal problem and at the same time providing a source of biomass energy. This study aims to investigate the feasibility of producing biocoal from lemongrass waste (*Cympobogon sp.*) by using microwave-induced torrefaction method. Torrefaction is a thermochemical process of upgrading the characteristics of biomass. In this study, the process was carried out within a narrow temperature range from 200°C to 300°C in an anoxic atmosphere. The torrefaction process was continued with pelletisation, where the torrefied *Cympobogon sp.* is converted into pellets. The physical, chemical and thermal characteristics of the raw *Cympobogon sp.* and the biocoal produced, such as proximate analysis, elemental analysis, surface morphology, surface chemistry, textural analysis, thermal stability, higher heating value (HHV), hydrophobicity, mass and energy yield with relate to the effects of microwave power and reaction time were determined. The highest microwave power level to achieve the torrefaction temperature range was 1000 W with reaction time of 30 minutes. The highest HHV and surface area achieved for torrefied *Cympobogon sp.* were 19.37 MJ/kg and 81.391 $m^2$/g, respectively. This study proved that the enhancement of the physical, chemical and thermal characteristics of the lemongrass (*Cympobogon sp.*) waste made it feasible to be converted into biocoal through microwave-induced torrefaction method.

# ABSTRAK

Penggunaan tenaga biomas boleh mengurangkan kesan pemanasan global dan pelepasan bahan toksik dan karsinogenik yang dihasilkan daripada penggunaan bahan api fosil. Dengan mengambil kira kuantiti besar sisa-sisa pertanian yang terbiar dan tidak dilupuskan dengan cara yang betul, ia boleh ditukar menjadi *biocoal* dengan rawatan yang tepat sekaligus dapat membantu menyelesaikan masalah pelupusan sisa serta menjadi sumber tenaga biojisim. Kajian ini bertujuan untuk mengkaji keberkesanan menghasilkan *biocoal* dari sisa serai (*Cympobogon sp.*) dengan menggunakan kaedah *torrefaction* gelombang mikro teraruh. *Torrefaction* adalah satu proses termokimia untuk menaiktaraf ciri-ciri biojisim. Proses ini dilaksanakan di dalam julat suhu yang terhad iaitu dari 200°C hingga 300°C, di dalam keadaan tanpa oksigen. Proses *torrefaction* diteruskan dengan *pelletisation*, di mana *torrefied Cympobogon sp.* akan bertukar menjadi *pellet*. Ciri-ciri fizikal, kimia dan haba *Cympobogon sp.* yang masih mentah dan *biocoal* yang dihasilkan, seperti analisis proksimat, analisis unsur, permukaan morfologi, permukaan kimia, analisis tekstur, kestabilan haba, *higher heating value (HHV), hydrophobicity*, jisim dan hasil tenaga yang berkaitan dengan kuasa gelombang mikro dan masa tindak balas dapat ditentukan. Tahap kuasa gelombang mikro yang paling sesuai untuk proses *torrefaction* ialah 1000 W dengan masa tindak balas selama 30 minit. Keputusan *HHV* dan analisis tekstur yang dicapai bagi *torrefied Cympobogon sp.* adalah 19.37 MJ/kg dan 81.391 $m^2$/g, masing-masing. Kajian ini membuktikan bahawa peningkatan fizikal, kimia dan haba ciri-ciri sisa serai (*Cympobogon sp.*) menjadikannya layak untuk ditukar menjadi *biocoal* melalui kaedah torrefaction gelombang mikro yang disebabkan.

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# LIST OF ABBREVIATIONS

| | | |
|---|---|---|
| BET | - | Brunauer-Emmett-Teller |
| C | - | Carbon |
| CO | - | Carbon Monoxide |
| $CO_2$ | - | Carbon Dioxide |
| DTG | - | Derivative Thermogravimetric |
| FTIR | - | Fourier Transform Infrared Radiation |
| H | - | Hydrogen |
| H/C | - | Hydrogen to Carbon Ratio |
| HGI | - | Hardgrove Grindability Index |
| HHV | - | Higher Heating Value |
| HTC | - | Hydrothermal Carbonization |
| LHV | - | Lower Heating Value |
| N | - | Nitrogen |
| O | - | Oxygen |
| O/C | - | Oxygen to Carbon Ratio |
| OH | - | Hydroxyl Group |
| S | - | Sulphur |
| SEM | - | Scanning Electron Microscope |
| TOP | - | Torrefaction and Pelletisation |
| TGA | - | Thermogravimetric Analysis |
| TW | - | Torrefied Wood |
| VCO | - | Volatile Organic Compound |

# LIST OF NOMENCLATURE

| | | |
|---|---|---|
| wt% | - | weight of percentage |
| ºC | - | degree celcius |
| ºC/min | - | degree celcius per minute |
| cm | - | Centimetre |
| db | - | decibel |
| GHz | - | Giga Hertz |
| $GJ/m^3$ | - | Gigajoule per metre cube |
| g | - | gram |
| kg | - | Kilogram |
| kJ/kg | - | Kilojoule per kilogram |
| kPa | - | Kilopascal |
| lm | - | lumen |
| MHz | - | Mega Hertz |
| MJ/kg | - | Megajoule per kilogram |
| m | - | Metre |
| mm | - | Milimetre |
| min | - | minute |
| psi | - | pound per square inch |
| W | - | Watt |

# CHAPTER 1

# INTRODUCTION

## 1.0 Introduction

Based on the Eighth Malaysia Plan which was implemented in 2001 to 2005, renewable energy has become the country`s fifth fuel source. Followed by the Ninth Malaysia Plan which was implemented in 2006 to 2009, the targeted production of electricity from renewable energy was 350MW (1.8% of the total energy mix). However, in December 2009, the percentage of renewable energy to the total electricity generation was still at its lowest stage, which was 55.5MW (less than 1% of the total energy mix). This shows that the Ninth Malaysia Plan had failed with its own target (TS, 2010). In order to overcome this problem, the Malaysia government has come out with the Tenth Malaysia Plan which commenced since year 2010. The main objective of the Tenth Malaysia Plan was to increase the renewable energy capacity up to 985MW (5.5% of the total energy mix) of Malaysia`s total electricity generation by the year 2015 (Razak, 2010).

At present, about 168 million tonnes of biomass, which includes the agricultural wastes, are being produced in Malaysia (CS, 2011). Usually, the agricultural wastes are being abundant or burnt, which will lead to various environmental pollution problems. In order to achieve the Tenth Malaysia Plan`s goal, the full utilization of agricultural wastes as one of the sources of biomass energy will give huge potential in producing biocoal, which is known as carbon-neutral fuel, for electricity generation.

## 1.1 Overview of Biomass

Concerning the finite source of fossil fuels and the consequences of its emissions to the environment, renewable energy is the alternative way to ensure the energy supply remains, and keeping the national and international infrastructure intact (Jared, 2014). Of all the sources for renewable energy such as wind, tidal and solar, biomass has become the most well-known contributor to the worldwide energy production. According to International Energy Agency (2013), biomass energy contributed approximately 10% of worlds total energy supply. Among the total biomass supply used for energy purposes, 60% of biomass were traditional biomass which included fuel wood, crop residues and animal dung. Commonly, biomass is used in developing countries for cooking, heating and lighting (WEO, 2006). In Malaysia, the potential uses of biomass, biogas and other renewable energy sources have been recognized since early year 2000 (Mekhilef, 2010).

Biomass can be defined as any organic materials that come from living or were living in the past. Lignocellulosic biomass is one of the major parts of biomass, mostly used as renewable energy and as a replacement of fossil fuels. Generally, lignocellulosic biomass comprises of three major constituents which are cellulose, hemicellulose and lignin. Biomass can be converted into various forms of fuel such as solid, liquid and gas, which are beneficial for energy production (Kambo & Dutta, 2014). Lucia (2008) stated that the processing of lignocellulosic biomass was less expensive compared to petroleum. It is mostly known as a carbon neutral energy resource as there is no addition or reduction of the amount of carbon in the atmosphere. Burning the lignocellulosic biomass in coal power plant does not add carbon to the environment which shows that the chemical contents have better impact to the environment. The statement was agreed by Ozcimen & Mericboyu (2010) and Kambo & Dutta (2014) as the uses of biomass can lower the effect of global warming from the existing fossil fuels-powered plants and the release of toxic and carcinogenic emissions.

Globally, the total biomass resources available are about 1800 billion tons on the ground and 4 billion tons in the ocean (ABH, 2008) The example of biomass resources include woody and herbaceous species, agricultural and industrial residues, municipal solid waste, sawdust and waste from food processing (Ozcimen & Mericboyu, 2010). According to Basu *et al.* (2014), biomass resources do not include organic material that has been transformed through geological processes such as petroleum. **Table 1.1** shows the biomass categorization in terms of use and applications.

As many types of biomass sources are available, the agricultural wastes are more preferable for energy production due to their large quantity of being disposed and being abundant, which will lead to pollution problems (Kishor *et al.*, 2014).

**Table 1.1**: Biomass categorization (ABH, 2008)

| Biomass | Example | |
|---|---|---|
| **Conventional biomass resources** | Agriculture, forestry (woody), fishery, livestock farming<br>E.g. food, materials, medicine, timber, pulp, chip | |
| **Biomass wastes (Derivatives)** | Agricultural, forestry, fishery, livestock residues (wastes)<br>E.g. rice straw, cattle manure, lumber mill, sawdust, sewage sludge, black liquor | |
| **Plantation biomass** | Forestry | : eucalyptus, poplar, willow |
| | Herbaceous | : sugarcane, switchgrass, sorghum |
| | Aquatic | : giant kelp, water hyacinth, algae |

The common characteristics of untreated lignocellulosic biomass are low heating value, low energy density, low combustion efficiency, high moisture content, hydrophilic and hygroscopic in nature, poor flowability, poor blending, tough and fibrous in nature, high biological degradation rate and poor structural heterogeneity (Batidziral *et al.*, 2013). These characteristics lead to difficulties in handling and storage of biomass. It is therefore beneficial to treat the biomass with proper thermochemical conversion technologies in order to improve its original characteristics as well as to achieve high quality products such as biocoal which can then be converted into useful biofuels for generating heat and electricity (Kishor *et al.*, 2014).

## 1.2 Overview of Biocoal

According to Kiuru & Hyytiäinen (2013), biocoal is a product of solid biomass that depends on certain process conditions after undergoing the pyrolysis process. Raw biomass which undergoes the hydrothermal carbonization will convert into coal-like-substance, also called as biocoal (Tremel *et al.*, 2012). Maheshwari & Chaturvedi (1995) stated that biocoal is a product from biomass which has been treated to improve its physical and chemical properties. For instance, the biomass is heated to certain temperature to make it hydrophobic in nature and proceed with pelletization process for easy storage and handling. Agar and Wihersaari (2012) interpreted biocoal as a coal substitute, where the raw materials are from the renewable biomass resources that has undergone the torrefaction process. The application is likely the same as conventional coal as it can be combusted in pulverised-fuel power plant. Several benefits were highlighted for the production of biocoal such as improved heating value, ability to displace the fossil coal usage and reduced electricity use for size reduction. In summary, biocoal is made up of various biomass resources, in which their properties have been upgraded to certain desirable products via several thermochemical processes such as pyrolysis, hydrothermal carbonization, gasification and torrefaction. Biocoal does not just provide solution for disposal of abundantly free biomass resources such as agricultural waste and food leftovers, it also has a great potential for generating income to the country as well as reducing the $CO_2$ emission. In UK, approximately 30 million tonnes of biomass waste are available annually, which can be converted into useful biofuels, which potentially result in the saving of 36 million tonnes of $CO_2$ (Antaco, 2014).

## 1.3 Thermochemical Conversion Technologies

Biocoal is a solid fuel made from biomass and commonly known as torrefied biomass, which has undergone thermochemical process in a low-oxygen environment (CSR, 2014). Biocoal has become the worldwide attraction due to its ability of increasing the biomass co-firing rates as well as reducing the carbon dioxide emission in pulverized-coal power plants (Ashton, 2013). There are various technologies used to produce biocoal from agricultural wastes such as hydrothermal carbonization, torrefaction, pyrolysis and gasification. **Table 1.2** shows a brief description about the technologies available to produce biocoal with their respective operating temperature range.

**Table 1.2**: Technologies used to produce biocoal.

| Technologies | Description | Operating Temperatures (ºC) | References |
|---|---|---|---|
| Hydrothermal Carbonization | Thermochemical process (especially for biomass waste having a high water content) to form solid residues, also known as wet torrefaction. Biomass waste is submerged in water and being heated in a confined system. | 180 - 250 | Kambo & Dutta (2014) |
| Pyrolysis | Chemical decomposition of a material in a closed system without the presence of oxygen at very high temperature range. | 300 - 650 | Chattipadhyay (2000) |
| Torrefaction | Thermochemical process which is carried out under atmospheric pressure at a lower temperature range, with the absence of oxygen, also known as mild pyrolysis. The process has to be carried out in an inert environment in order to prevent combustion and maintaining the anoxic circumstances. | 200 - 300 | Wang *et al.* (2012) |
| Gasification | Incomplete combustion of biomass, which results in the production of combustible gases consisting of CO, $H_2$ and traces of $CH_4$. | 1000 | Anil (2014) |

## 1.4 Problem Statement

In recent years, biomass has been sought after as a major source of renewable energy. Among all the biomass sources, agricultural wastes are the most promising in terms of their abundance and non-association with the food versus fuel problem. At present, agricultural activities have become the main source of Malaysia`s economic development due to its availability of resources and meeting the global demand. The handling of agricultural wastes and residues produced from the agricultural activities is the most critical challenge to the industry. The waste is commonly being abundant and burnt without proper procedure, which will lead to environmental problems. Conversion of the agricultural waste into biocoal by using thermochemical conversion technologies has become the main attraction of most manufacturers and researches nowadays.

There have been several studies reported on torrefaction of biomass. However, most of the studies used electric or conventional heating method as the heating source. Conventional heating-based torrefaction generally requires longer processing time. This is mainly because of the concept of transferring heat into materials by conduction, convection and radiation. On the other hand, microwave-induced torrefaction uses the concept of transferring heat into the materials by molecular interaction within the electromagnetic field provided by microwave energy. Wang *et al.* (2012) in their study of microwave-induced torrefaction of rice husk and sugarcane residues has reported that the torrefaction process using microwave heating was an efficient and promising technology with a great potential in producing high quality fuel. The improvement of physical and chemical characteristics of the agricultural wastes through torrefaction process will produce a high quality biomass product, and at the same time, the waste disposal problem is solved. The conventional fuel which is known by its drawback in adding carbon to the environment will then be replaced with biocoal, which is a carbon-neutral fuel.

Huszalina (2015) stated that the agricultural waste produced in Malaysia especially lemongrass waste consisted of high hemicellulose content which was 58% from its original composition. Approximately, there was 100 hectares of lemongrass farm available in Malaysia and the production of dry bagasse was about 200 tonne per year. Generally, the lemongrass waste such as leaves and stalk were left dried, burned and naturally degraded in the fields without proper handling methods.

Up to date, no study has been reported in the literature on the potential of conversion of lemongrass wastes into biocoal. Therefore, this study aims to investigate