MICROWAVE ASSISTED TORREFACTION OF PLANTATION RESIDUES AND KITCHEN WASTE

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MICROWAVE ASSISTED TORREFACTION OF PLANTATION RESIDUES AND KITCHEN WASTE

by

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LIST OF SYMBOL

O/C	Oxygen to carbon ratio
H/C	Hydrogen to carbon ratio
θ_{tor}	Torrefaction temperature
$t_{heating}$	Reaction time
$H_2 0$	Water
CH_4	Methane
H_2	Hydrogen gas
N_2	Nitrogen gas
℃	Degree Celsius
MJ/kg	Mega joules per kg
Min	Minutes
W	Watt
$\pm$	More than or less than
T_{cor}	Correction temperature
t_c	Beckmann's thermometer reading
t_a	Ambient temperature
m_{we}	Mass of water equivalent
m_w	Mass of water
C_{pw}	Specific heat of water
E_{rice}	Energy of rice paper
$E_{nichrome}$	Energy of nichrome wire
l_i	Initial length of nichrome wire

l_f	Final length of nichrome wire
$m_{charcoal}$	Mass of charcoal
$m_{charcoal,raw}$	Mass of raw material
$m_{charcoal,torrefied}$	Mass of torrefied material
HHV_{raw}	Higher heating value of raw material
$HHV_{torrefied}$	Higher heating value of torrefied material
kWh	Kilo watt hour
kJ/kg	Kilo joule per kg
ε	Emissivity of material
ε'	Dielectric constant
ε''	Dielectric loss factor
ε*	Complex dielectric constant
Hr	Heating Rate

Permittivity of free space (8.85 x 10^{-12} F m^{-1})

LIST OF ABBREVIATION

MSW	Municipal solid waste
HHV	Higher heating values
EFB	Empty fruit bunch
PKS	Palm Kernel Shell
TCD	Thermal Conductivity Detector
TGA	Thermogravimetric Analyzer

TOREFAKSI BERBANTU MIKROGELOMBANG BAGI SISA PERLADANGAN DAN SISA DAPUR

ABSTRAK

Lembapan dan jirim meruap perlu dikeluarkan dari biojisim untuk menukarnya menjadi arang. Antara kaedah yang ada, proses torefaksi ialah kaedah yang paling menarik untuk menukarkan biojisim menjadi arang. Walau bagaimanapun, proses torefaksi yang biasa digunakan menggunakan mekanisme pemanasan konvensional yang menggunakan tenaga elektrik yang tinggi. Tindak balas ini biasanya dijalankan di 250-300 ^{0}C dan kadar pemanasan biasanya disimpan di bawah 50 ^{0}C / min. Pemanasan biojisim berlaku dari permukaan ke bahagian dalam zarah melalui konduksi, perolakan dan sinaran dan kadar pemanasan itu lebih tinggi boleh menyebabkan masa pemprosesan yang lebih pendek dan juga menyebabkan tindak balas yang tidak lengkap. Berbeza dengan ini, dalam ketuhar gelombang mikro, pemanasan berlaku pada peringkat molekul dan pemanasan isipadu dicapai.

Oleh itu , produk torefaksi setanding boleh diperolehi dalam pemanasan gelombang mikro pada tahap kuasa yang rendah dan masa yang lebih pendek , yang boleh menjimatkan tenaga dan masa dalam proses. Dalam projek ini, tenaga gelombang mikro digunakan untuk menukar sisa pertanian dan sisa dapur sebagai arang melalui proses torefaksi. Ketuhar gelombang mikro komersial telah diubahsuai dan mempunyai ciri-ciri untuk proses torefaksi.

Sistem ini dicirikan berdasarkan masa, suhu dan tahap kuasa gelombang mikro yang sepadan dengan kadar pemanasan yang lebih rendah daripada 50 ^{0}C / min. Nilai pemanasan arang yang diperolehi dalam projek ini adalah di antara 14MJ /

kg dan 39MJ / kg bergantung kepada jenis bahan torefaksi dan masa tinggal torefaksi. Produk torrikfasi telah dicirikan dari segi komposisi unsur, tenaga dan hasil besar-besaran, dan jumlah tar. Produk gas dari torefaksi dari jenis yang berbeza bahan juga dianalisis. Gas keluar daripada proses torefaksi yang dianalisis menggunakan Gas Chromatography manakala, kandungan kelembapan, karbon tetap telah ditentukan dengan menggunakan (TGA). Keputusan eksperimen menunjukkan bahawa proses torefaksi bawah penggunaan tenaga yang rendah penyinaran gelombang mikro sesuai untuk proses torefaksi. Proses torefaksi untuk sisa makanan dan pisang kulit suhu ketuhar adalah 250 ℃ dan untuk isirong sawit dan buah tandan kosong masing-masing mengunakan suhu ketuhar 270 ℃ dan 300 ℃. Hasil keputusan selepas proses torefaksi, sisa makanan dan kulit pisang mempunyai lebih rendah daripada 10% kandungan kelembapan kulit isirong sawit berbanding dan buah tandan kosong yang mempunyai lembapan 40% dan 10% masing-masing.

Kandungan lembapan untuk sisa makanan dan kulit pisang masing-masing 5.33% dan 2.57%. Nilai pemanasan (HHV) adalah 20.81, 21.63 dan 22.15 MJ / kg untuk masa yang torrifaksi 30 min untuk isirong sawit, dan sisa makanan dan 40 min untuk kulit pisang masing-masing. Ini boleh menyumbang kepada reaksi torefaksi yang mengeluarkan meruap dan penguraian yang lignocelluloses biojisim. Untuk hasil yang besar-besaran, permulaan nilai berkurangan apabila masa torefaksi bertambah pada jarak 10 hingga 30 minit pada suhu 300 ^{0}C. Untuk bahan biomass (buah tandan kosong, isirong sawit, kulit pisang dan sisa makanan) apabila suhu mencapai julat suhu yang lebih tinggi 270-300 ^{0}C hasil tenaga akan berkurang kerana hasil jisim lebih rendah.

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ABSTRACT

Moisture and volatile matter in biomass material should be removed to convert it into char. Among the available methods, torrefaction process of biomass material is the most attractive method converting biomass into char. However, the commonly applied torrefaction process use conventional heating mechanism that consumes high electrical energy. The reaction is usually carried out at 250–300 ^{0}C and the heating rates are usually kept below 50 ^{0}C/min. The heating of the biomass takes place from the surface to the inside of the particle through conduction, convection and radiation and therefore higher heating rates may result in shorter processing time and also result in incomplete reaction. In contrast to this, in microwave, heating takes place at a molecular level and volumetric heating is achieved.

Thus, comparable torrefaction products can be obtained in microwave heating at low power levels and much shorter time, which can save both energy and time in the process. In this project, microwave energy is used to convert plantation residues and kitchen waste into charcoal via torrefaction process. A commercial microwave oven was modified and characterized for torrefaction process.

The system is characterized based on time, temperature and microwave power level corresponding to heating rate lower than 50 ^{0}C/min. The heating values of the charcoal obtained in this project ranges from 14MJ/kg to 39MJ/kg depending on the types of torrefied material and the torrefaction residence time. The torrefied

products were characterized in terms of their elemental composition, energy and mass yields and amount of tar. The gaseous products from torrefaction of different types of materials were also analysed. The output gas from the torrefaction process was analysed using gas chromatography, whilst, moisture content, volatile and fixed carbon had been determined using thermogravimetric analyzer (TGA). The experimental results showed that torrefaction process under low energy consumption of microwave irradiation is suitable for torrefaction process. For waste food and banana peel torrefaction, the oven temperatures was 250℃ and for palm kernel shell (PKS) and empty fruit bunch (EFB) torrefaction, the oven temperatures were 270 ℃ and 300 ℃ respectively. The result after torrefaction process, shows that the waste food and banana peel have lower than 10% moisture content compared to palm kernel shell (PKS) and empty fruit bunch (EFB) which have 40% and 10% respectively of moisture content.

Moisture content for waste food and banana peel were 5.33% and 2.57% respectively. The heating value (HHV) of torrefied char were 20.81, 21.63, and 22.15 MJ/kg for the torrefaction time of 30 min for palm kernel shell (PKS), and waste food and 40 min for banana peel respectively. This may be contributed by the torrefaction reaction in removing the volatiles and decomposing the lignocelluloses of biomass. For the mass yield, the value started decreasing when torrefaction time increased from 10 to 30 minutes at the temperature 300 ^{0}C. For biomass material (PKS, EFB, waste food and banana peel) once temperature reached the higher temperature range of 270 to 300 ^{0}C the energy yield reduces because of lower mass yield.

CHAPTER 1: INTRODUCTION

1.1 Research Background

Fast depletion of the fossil-based energy reserves, increase in energy consumption and greater environmental awareness for global climate change due to CO_2 emissions have encouraged studies to look for greener sources of energy as alternatives to replace the fossil fuels. Therefore, research activities on renewable energy sources have become more and more important.

Most of the time, agriculture wastes are not appropriately disposed. The majority of the agriculture waste combustion produce air pollution. Actually, with technological advances, agriculture waste can be converted into a more useful form of energy (Deng et al., 2009). The efficient usage of agriculture waste to supply energy turns out to be more relevant in view of fossil/fuel deficiency and ecological issues created by energy utilization.

Kitchen waste degradation emits methane (CH_4), which constitutes 50 % to 55 % by volume of landfill gas (LFG) and has 21 times the global warming potential than CO_2 (Chiueh et al., 2012). Furthermore, land filling also causes pollution that will risk the nearby residents' health.

As Malaysia targets to reach economically in this competitive world, the nation is enhancing its fuel supply portfolio. Petroleum, different liquid and natural gas are the crucial sources in Malaysia with evaluated shares of 40% and 36%, independently in 2012 as shown in Figure 1.1.

Around 17% of the nation's energy utilization is met by coal. Biomass and waste contribute 4%, and hydro power helps 3% of the aggregate used. (Malaysian primary energy consumption, 2012). Among all renewables energy, biomass is the most widely used energy source worldwide. However, almost half of renewable energy come from an inefficient biomass process for cooking and heating in developing countries. However,its energy density is lower than fossil fuel; this leads to the low utilization efficiency when biomass is directly consumed as a fuel. To overcome this disadvantage, the energy density of biomass can be improved via physical or thermal processes

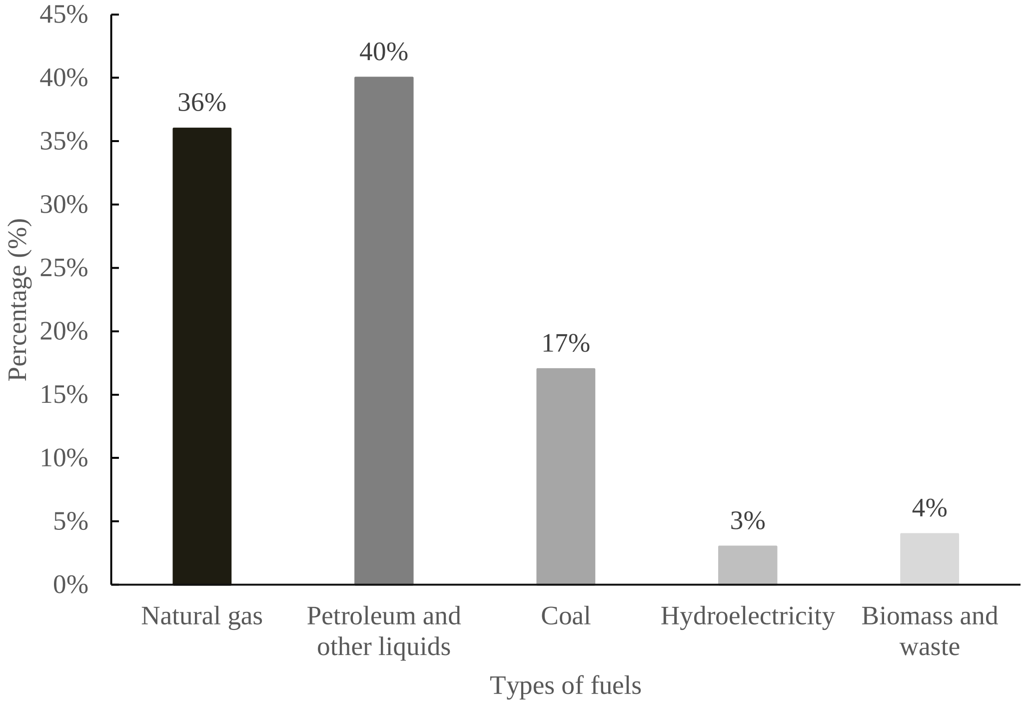

Figure1.1: Malaysian primary energy consumption, 2012

Thermo-chemical process is an efficient conversion of biomass into energy. One of the thermo-chemical processes is torrefaction. In this process, biomass is converted into other forms of energy. It has potential for rural electrification projects particularly in third world countries where biomass supplies from agricultural industries are abundant and where electricity supply from the grid is not available (Malaysian primary energy consumption, 2012).

1.2 Problem Statement

Although various efforts of torrefaction process have been performed and proven technically effective but from an economic point of view, efficient char production still remains the major technical obstacle to the success in commercialization of biomass torrefaction technologies. In general, overall process of existing torrefaction process is costly and high energy demand. This is because majority of torrefaction research is directed at conventional heating mechanism using an external high electrical source where heat transfer occurs from the surface to the core of the material. Moreover, the reactor can also be limited within a conventionally/electrically heated reactor due to the heat/mass transfer limitations as the heat is supplied from the external wall in most of the conventional heating reactors (Bhattacharya et al., 2011). Other disadvantages are slow heating process, high heat losses and high heat transfer resistance that can damage the reactor walls due to continuous electrical heating (Salema and Ani, 2011).

For this reason, implementation of microwave energy for torrefaction process would be a more realistic option as an alternative method to solve the limitations of conventional heating method. In this method, the transfer of energy into the material occurs instantaneously through molecular interaction with the electromagnetic field (Thostenson and Chou, 1999). The volumetric heating of materials using microwave can result in significant energy savings, reduce process time and increase process yield (Motasemi and Afzal, 2013).

Small domestic system to torrefy kitchen waste is not available in market. There is a need be develop such a system for domestic use. Small scale domestic system required less energy consumption and affordable. Besides that, it can be easily used at home and not required complex big scale system. Thereby, in this work, torrefaction of biomass under small scale microwave heating will be performed. Different microwave power, temperature, residence time, and biomass materials will be explored.

In this project, plantation residues and kitchen wastes are selected to be torrefied by using a domestic microwave oven.

1.3 Objectives of the Study

The specific objectives are to:

- To modify a domestic microwave oven into a torrefier
- To produce torrefied material from various source at different temperatures and resident time
- To determine energy, mass yield and performance of the microwave torrefaction system

1.4 Scope of the Thesis

A domestic microwave oven will be purchased and modified for this study. This project includes the conversion of plantation residues and kitchen wastes into char by utilizing torrefaction process. Two types of agricultural materials and two types of kitchen wastes will be converted into char through torrefaction process. Ceramic container will be used for the torrefaction and the torrefaction process will be conducted at various temperature of 250°C, 260°C, 270°C, 280°C 290°C and 300°C.

The torrefaction times will be varied from 10 minutes, 20 minutes, 30 minutes, 40 minutes, 50 minutes and 60 minutes.

Then, the suitable temperature level and time will be determined suitable for torrefaction. The higher heating values (HHV) for the char obtained will be tested and microwave energy consumption of the system will be calculated. Proximate analysis, analytical analysis, tar content, and gas components in the producer gas also will be investigated. Furthermore, energy and mass yield as well as the system efficiency for different sample at a different torrefaction time will be studied. The effect of torrefaction time and biomass on the microwave consumption, HHV, proximate analysis, analytical analysis, tar content, and gas components in the producer gas and the system efficiency will be determined.

Finally, the system will be characterized according to its suitable torrefaction time, power level and temperature level for different biomass materials.

1.5 Outline of the Thesis

This thesis includes five chapters which are the introduction, literature review, methodology, results and discussions and the last one is the conclusions.

In the introduction, overview of the project, problem statements, objectives and the scope of the research are outlined. This chapter is very important so as the purposes of doing this research, expected outcomes, and the coverage of this research are justified.

In the Literature Reviews chapter, the overview of torrefaction, microwave heating, Malaysia's plantation residues and municipal solid waste generation, microwave torrefaction are studied. This is important so that the principle of microwave torrefaction is well understood in order to conduct the experiment**.**

Furthermore, other findings are studied so that there are no repetitions of previous works.

In the Methodology chapter, the path to conduct the experimental microwave torrefaction is outlined and clarified. The interpretations of the findings are also outlined so that the flow of this project is clarified.

In the Results and Discussions chapter, all the data are analysed and graphs are plotted. The relationship between the manipulated variables and the responding variables are interpreted. All these relationships are justified according to principles and findings from literature reviews. The results from this experimental testing are compared to previous works and discussed.

Last but not least, all the findings in this project are summarized in the conclusion. The objectives of this project are justified or else recommended for further study in the future.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

Biomass can be exploited to produce energy by thermochemical treatment, anaerobic digestion or esterification. As of late, the treatment of biomass at low temperatures going from 200 ^{0}C to 300 ^{0}C under an inert environment was discovered to be successful in enhancing the energy density of the biomass. This treatment is referred to as 'torrefaction' (Poudel et al., 2015).

A lot of research have been done on conventional torrefaction and a microwave torrefaction to find the most suitable torrefaction conditions for torrefaction as well as discover the reason why microwave torrefaction should be considered.

Four thermochemical process, including combustion, gasification, pyrolysis and torrefaction are being used for converting biomass into valuable coefficient fuel of energy. Pyrolysis creates liquid bio-oil and solid fuel, which is tantamount to coal and is termed as bio-coal (Asadullah et al.).

Torrefaction is a partial pyrolysis process that includes heating biomass at temperatures of 200–300 ^{0}C in the absence of oxygen, amid which the biomass mostly decays, discharging diverse sorts of volatiles. Significant energy densification can be attained to by torrefaction, contains up to 90% of the energy yet just 70% of the starting weight of the biomass feedstock (Nunes et al., 2014). Torrefaction reduces the moistures in biomass and changes the hygroscopic biomass to a hydrophobic material, rendering the low affinity of water in torrefied biomass. Thus, the torrefied materials can be put away for quite a while and its usage efficiency is