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PRODUCTION AND KINETIC STUDY OF TORREFIED OIL PALM FROND AND *LEUCAENA LEUCOCEPHALA* PELLETS FOR CO-COMBUSTION WITH SILANTEK COAL

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ABSTRACT

Biomass in Malaysia has potential to be converted into high quality solid biofuels by enhancing properties of raw biomass via combined process of densification and torrefaction. Torrefaction, also known as mild pyrolysis, is generally carried out between temperature range of 200 and 300 °C in anoxic conditions, where it has favourable effects on biomass, which includes increasing its energy density and eliminating problems commonly associated with raw biomass such as high moisture content, hygroscopic behaviour and low calorific value. In this study, torrefaction of agricultural plantation residue, oil palm frond (OPF, non-woody biomass) and short rotation energy crop, *Leucaena Leucocephala* (LL, woody biomass) were conducted in a horizontal tube furnace at five temperatures and holding time of 15–60 min. These torrefied biomass pellets can be used as a highly viable feedstock in thermochemical processes such as gasification and as a substitute to coal in thermal power plants and metallurgical processes. Torrefaction is influenced by many factors where among the strong factors are biomass lignocellulosic composition, temperature and residence/holding time. Results obtained in this study showed high energy densification factor of produced biomass pellets in the maximum range of 1.46–1.50, calorific value increment of 50–54%, and improved hydrophobicity at 23–35%. Via FTIR, the most significant structural changes brought by torrefaction were on the hydroxyl stretch (–OH) and C–O stretch due to the reductions of hydrogen and oxygen atoms in the biomass structure where consequently, lignin-related concentrated bonds are high and atomic ratios O/C and H/C reduced significantly causing favourable fuel ratio to increase up to 1.06. In order to obtain sufficiently high mass-energy properties, optimisations via response surface methodology (RSM) incorporating central composite design (CCD) were carried out. Results showed temperature is the most influential factor during torrefaction process while holding time effect was absent for oil palm frond and very minimal for *Leucaena Leucocephala*. Torrefaction and co-combustion kinetic studies were performed via non-isothermal thermogravimetric analysis. The most reliable method was identified to be Coat-Redfern method with high correlation coefficients ($R^2 \geq 0.965$) for both processes. Via this method, reaction mechanisms during torrefaction were identified to be reaction order and diffusion for OPF and LL, respectively. As for co-combustion kinetic study, both torrefied biomass and Silantek coal followed diffusion reaction mechanism. Co-combustion of coal and torrefied biomass was dominated by char combustion stage, in which activation energies of the blends decreased up to 43% where the lowest E_a was obtained at 40% TOPFP (77.33 kJ/mol) and at 50% TLLP (65.30 kJ/mol). The information regarding biomass torrefaction and combustion/co-combustion kinetics is needed to accurately predict reactions behaviour, as well as to optimise and control the process of conversion toward products during the thermal degradation.

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CHAPTER ONE
INTRODUCTION

1.1 Research Background

1.1.1 Overview of Energy Situation in Malaysia

Malaysia is a fast-developing country that aspires to achieve high-income status by 2020 where its economic growth is heavily dependent on its abundant energy resources, particularly non-renewable sources such as natural gas and crude oil. At present, the most critical challenge faced by energy sectors is the continuous supply of energy i.e. energy security and diversification of energy resources. Malaysian government policies with regards to energy, particularly, electricity supply have traditionally been based on fossil fuels. Based on Malaysia Energy Statistic Handbook 2017, non-renewable energy sources contributed over 86% (135.2 GWh) of electricity generation mix [1]. A large portion of electricity generation (~41%) originate sfrom coal-fired power plants which have been introduced in Malaysia for over two decades, in which coals are 99% imported from Indonesia, China and South Africa [1,2]. Despite growing concerns of coal's detrimental impacts to the environment, its contribution in Malaysia's electricity generation mix in 20-years span has increased by 15 times from 4177 GWh in 1996 to 66246 GWh in 2016, with total imports of 16.1 Mtoe [1,3]. By year 2030, coal utilisation in electricity generation sector is expected to rise four-fold whereas natural gas is targeted to be reduced by half [3]. Thus, Malaysia will continue to rely on imported coals for the purpose of energy security, albeit the global's pressure to reduce greenhouse gas (GHG) emissions.

Realizing the over-dependency on fossil fuels as energy source, Malaysia has been committed to diversify its fuel source where policies on fuel diversification were first introduced in 1999 to promote renewable energy (RE) usage. Malaysia is blessed with indigenous generation mix of renewable energy resources such as biomass and biomass materials (oil palm mill/plantation residues, forestry biomass, agro-based and farming industries biomass waste), mini-hydro power, solar power and wind energy [4]. As a signatory to the Montreal and Kyoto Protocols, Malaysia has been supporting renewable energy as the fifth fuel since year 2001 while encouraging greater energy