



Characterisation of Malaysian wood pellets and rubberwood using slow pyrolysis and microwave technology



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ABSTRACT

A series of biomass wastes from Malaysia known as Malaysian wood pellets, and rubberwood were employed in the present work. Using these materials as the feedstock, two different heating techniques; external heating by means of conventional slow pyrolysis (SP) and instantaneous volumetric heating by means of microwave pyrolysis (MP) were carried out. Two distinct temperatures; 500 °C and 800 °C were used. The main objective was to characterise both the microwave-pyrolysed products and slow pyrolysed products together including the influence of temperature so as to compare and contrast in terms of yield, and composition of the high-value fuel gas (H_2) or syngas ($H_2 + CO$). The research found that the use of the microwave oven system to conduct pyrolysis boosted the production of oil but diminished the total gas yield. Char proportion also reduced when microwave heating method was applied. This research also revealed that the configuration of the microwave oven with mode stirrer and bottom-fed waveguide that produces a constant output power of 1000 W at any set temperature has yielded different results when compared to previous studies and so provides a new insight to the microwave pyrolysis community. The results demonstrated that the microwave-pyrolysed chars were slightly porous than slow-pyrolysed chars at 500 °C. However at higher temperature of 800 °C, lower surface area was obtained from microwave pyrolysis which can be attributed to serious damage of char structure as the consequence of high power supplied into the cavity and high temperature used. SEM microphotographs revealed that microwave pyrolysis at 500 °C led to the formation of char with clearly defined pore structure. In the case of gas product, both heating approaches were found to produce a comparable level of $H_2 + CO$ content except to those produced by MP at higher temperature (800 °C). Regarding bio-oil quality, the microwave-pyrolysed oil was found to present compounds with higher aliphatic content and contain less polycyclic aromatic hydrocarbon (PAH) content that is an added quality value as PAH is toxic to the environment.

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1. Introduction

Recently, there is a growing trend for researchers to look for an energy alternative to substitute fossil fuels. The world population has been increasing every year thus increasing the energy demand. To meet the energy needs has resulted in fossil fuels becoming more and more deplete and this gives rise to an alarming situation and uncertain future. Burning fossil fuels result in many drawbacks to the climate particularly due to the CO_2 emissions. In Malaysia, the recent climate change performance index was very poor and ranked Malaysia 49th out of the top 61 most polluted countries [1]. UK emission level, on the other hand, is still relatively high however

the country's climate change performance was rated as 'good' and ranked 3rd out of 12 leading countries that managed to reduce their emission levels. These results imply that there is an urgent need for new green energy, and one of the highest potential sources is biomass.

Biomass has been popularly regarded as clean and renewable, and its role in the energy market is also becoming increasingly pivotal. Biomass is an abundant source of energy after oil, coal, and natural gas [2]. The rubber industry in Malaysia is increasingly losing favour, mostly because of the rapid growth of the neighbouring countries, Indonesia and Thailand as major rubber producers in the world [3]. In fact, the global reduction in price of natural rubber follows the discovery of synthetic rubber and its extensive utilisation thereby giving a significant impact on the expansion of rubber plantation in the country. Additionally, the decline in rubber production in recent years also is due to the labour shortage and the conver-

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sion of rubber production land to other crops and uses. In Malaysia, the important source of rubberwood waste comes from replanting activities after 25 years latex yielding period and conversion of the rubber production land to palm oil trees. It has been estimated that a gross yield of rubberwood per hectare would be around 180 m³ [4] and based on the replanting rate of 3% in the country, the total waste production was estimated to be 5.4 million m³ [3]. The use of waste rubber trees after their productive life end is therefore, an ideal economical source of biomass to substitute fossil fuels.

Pyrolysis is one promising option for energy recovery from biomass, generally in the form of solids, liquids, and gases, produced by heating the biomass under an inert condition (absence of oxygen). These products are highly promising fuels to replace the exhaustion of conventional fuels and mitigate the environmental problems. They are also valuable and reusable, therefore potentially resaleable. Depending upon the operating conditions, the pyrolysis can be classified into two basic modes: slow pyrolysis and fast pyrolysis. These subclasses of pyrolysis differ by; reaction temperature, process condition, heating rate and also particle size of the feedstock. Slow pyrolysis, also referred to as conventional pyrolysis has been practised since thousand years ago and is still used these days for maximising char production. Fast pyrolysis differs significantly from slow pyrolysis where the process is associated with a greater control of the product target. For maximising bio-oil, very fine particles are treated at a temperature normally below 650 °C, with a rapid heating rate, and a very short residence time of <2s, and rapid quenching is highly necessary. On the contrary, a high temperature with a fairly high heating rate and long vapour residence time would favour maximum gas yield. The shorter vapour residence time of exposure of the organic matter (e.g., biomass) to heat during fast pyrolysis results in a pronounced period of heat and mass transfer, as well as phase transition along with chemical reaction kinetics [6]. Increasing the residence times to 10–20 s however, leads to secondary reactions of the products to occur at significant degree.

In conventional pyrolysis, the process efficiency is also highly dependent on the fundamental heat transfer processes of conduction, convection and radiation. This limitation has consequently driven the pyrolysis community to investigate an alternative technology for producing bio-derived and bioenergy products. Microwave pyrolysis technology is therefore seen as the best way to overcome the limitation of conventional heat transfer.

Microwave heating has long been known due to its high importance for a diversity of industrial processes such as tempering, thawing food, continuous baking, drying ceramics, rubber industries as well as many specialised process in the chemical industry [7]. Recently, there has been a rapid growth of interest for its potential use in the thermochemical treatment of various waste materials, including biomass such as wood and agricultural residues, algae, plastics, and municipal solid waste, and others. For example, the biomasses investigated include wood [8], pine wood sawdust [9], corn stover [10,11], corn stalk bale [12], rice straw [13,14], fir sawdust [15], Douglas fir pellets [16], coffee hulls [17], peanut shell and maize stalk [18], wheat straw [19], algae [20], oil palm biomass [21,22] and oil palm empty fruit bunches [23,24]. The application of microwave treatment is still at an early stage of development and therefore investigation of the principal lying behind this emerging technology is perceived as highly crucial. It has been noted widely in published literature that microwave heating is perceived as a highly attractive technique to provide an instantaneous volumetric heating process at significantly higher efficiencies as compared to conventional heating. Conventional thermal heating involves an energy transfer from an external source to the core of the sample via radiation, convection, and conduction, whereas microwave heating involves the conversion of electromagnetic energy to thermal energy within the

sample [25]. Therefore, microwave heating is defined as an energy conversion instead of heat transfer [26] and it has been reported to be an energy-efficient and viable alternative to conventional pyrolysis [27].

Previous literature has indicated that applying microwave pyrolysis instead of conventional pyrolysis results in higher char porosity, greater syngas production (H₂ + CO) and greener bio-oil production due to absence of carcinogenic compound of PAH. The core objective and focus of the present project are to investigate how far the microwave technology meets the requirement in terms of product quality improvement. The effects of microwave processing without the aid of microwave absorbers on different types of biomass are studied in depth in temperature ranges associated with pyrolysis together with comparing and contrasting the useful products obtained from microwave pyrolysis technology with those obtained from slow pyrolysis. In particular, characterisation of the carbonaceous residue (char), bio-oils and gases produced from both thermal systems are carried out by using various methodologies.

2. Experimental

2.1. Biomass

Two types of samples originating from Malaysia were employed for this project and they are described herein as rubberwood and Malaysian wood pellets. The rubberwood used in the present work was supplied by a farmer who has planted many rubber trees in Malaysia. The rubber tree branches, having in average 26 mm in diameter and less than 600 mm length was cut down as they were old and no longer able to produce latex. The rubberwood was then chopped into small cubes (approximately 15 mm × 15 mm × 15 mm). The second sample, Malaysian wood pellets (approximately 8 mm diameter × 40 mm length) were purchased from Dinxings (M) Sdn. Bhd., Malaysia. These wood pellets are originally made from sawdust produced by wood processing and furniture factories, sawmills, etc. Proximate analysis, ultimate analysis, and elemental analysis were carried out to determine the chemical characteristics of both raw materials used herein as the feedstock. The proximate analysis as a method for determining moisture content, volatiles, fixed carbon, and ash of the woody samples was carried out using a PerkinElmer TGA 4000 Thermogravimetric Analyser with the following conditions; about 15–25 mg of samples was heated at a rate of 20 °C/min from 40 °C to 900 °C in a nitrogen atmosphere. Then, the inert gas was switched into oxygen gas at a heating ramp of 10 °C/min until the temperature reached to 950 °C. This analysis was conducted according to ASTM Standard Test Method E870–82. The ultimate analysis (C, H, N and O by difference) was carried out using Organic Elemental Analyser Flash 2000 Series with the following conditions; sample was heated from 900 °C to 1000 °C with an addition of oxygen to burn the organic and inorganic material. As a result, elemental gases were produced and they passed through a separation column and a thermal conductivity detector which allowed for the determination of the elemental concentration. This method is certified by official organisations including the ASTM (American Society for Testing Materials) and the AOAC (Association of Official Analytical Chemists). The gross calorific value was determined using a Parr 6200 Oxygen Bomb Calorimeter. Table 1 shows the results of these analyses for both feedstocks. The elemental analysis was conducted by Inductively Coupled Plasma Mass Spectrometry (ICP-MS) using 7500cx Agilent ICP-MS and the result is shown in Table 2. With CV between 17 and 20 MJ/kg, high fixed carbon and volatiles, low O/C and H/C ratios, ash and moisture content less than 10 wt.%, Malaysian wood pellets and rubberwood are found to be very attractive potential

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