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Research article

Pyrolysis production of fruit peel biochar for potential use in treatment of palm oil mill effluent

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ABSTRACT

Fruit peel, an abundant waste, represents a potential bio-resource to be converted into useful materials instead of being dumped in landfill sites. Palm oil mill effluent (POME) is a harmful waste that should also be treated before it can safely be released to the environment. In this study, pyrolysis of banana and orange peels was performed under different temperatures to produce biochar that was then examined as adsorbent in POME treatment. The pyrolysis generated 30.7–47.7 wt% yield of a dark biochar over a temperature ranging between 400 and 500 °C. The biochar contained no sulphur and possessed a hard texture, low volatile content (≤34 wt%), and high amounts of fixed carbon (≥72 wt%), showing durability in terms of high resistance to chemical reactions such as oxidation. The biochar showed a surface area of 105 m^2/g and a porous structure containing mesopores, indicating its potential to provide many adsorption sites for use as an adsorbent. The use of the biochar as adsorbent to treat the POME showed a removal efficiency of up to 57% in reducing the concentration of biochemical oxygen demand (BOD), chemical oxygen demand COD, total suspended solid (TSS) and oil and grease (O&G) of POME to an acceptable level below the discharge standard. Our results indicate that pyrolysis shows promise as a technique to transform banana and orange peel into value-added biochar for use as adsorbent to treat POME. The recovery of biochar from fruit waste also shows advantage over traditional landfill approaches in disposing this waste.

1. Introduction

Fruits such as banana and orange are largely consumed in the world which consequently generates a significant amount of fruit peel wastes from the fruit processing industries. There were approximately 20 million tons of orange peels and 350,000 tons of banana peels being generated per year by the food industry (Aguiar et al., 2008; Housagul et al., 2014). The fruit peels are usually

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disposed by landfilling, open burning, and composting, which are becoming increasingly impractical due to environmental concerns such as emission of CH_4 as greenhouse gas from landfilling, possible discharge of toxic compounds (e.g. dioxin) from open burning (Kimbrough and Jensen, 2012), and the poor air quality arisen from the odour released during composting (Bu et al., 2014). These fruit peels, generated as a waste in large volume, also represent a biomass resource that can be recovered for further use rather than simply disposed by those impractical conventional methods.

Pyrolysis has recently been researched as a promising technique to generate useful products from biomass materials (e.g. fruit wastes, rice straws, microalgaes, oil palm shell) (Lam et al., 2016b, 2017a; Lin et al., 2014; Yek et al., 2017). It is a thermal decomposition process that heats and decomposes biomass materials in an inert environment to produce bio-oil, gases, and biochar (Liew et al., 2017). The pyrolysis process can be optimised to maximize production of any of these products by altering the process parameters such as pyrolysis temperature and residence time (Lam et al., 2017b). For example, pyrolysis performed at higher temperature (700–1000 °C) with a shorter residence time (from seconds to minutes) will obtain bio-oil and gases as main products (Lam et al., 2016c; Wan Mahari et al., 2017, 2016). In contrast, lower pyrolysis temperature ($\geq$ 500 °C) with a longer residence time (up to 1 h) will produce a higher yield of biochar (Collard and Blin, 2014).

There has been an increasing interest on the use of pyrolysis to carbonize biomass waste and residues from agriculture and forestry to produce biochar. Biochar is a porous and carbon-rich solid product with potentially wide applications (Nam et al., 2018). It shows potential to be used as adsorbent in water, air and gas purification (Ioannidou and Zabaniotou, 2007; Lompe et al., 2016). It could also be used as additive to improve soil fertility by increasing the microbial activity and nutrient in the soil (Lehmann et al., 2011). Alternatively, it can be used as solid fuel (Liu and Han, 2015) or in carbon fuel cell to produce electricity (Qian et al., 2015). In addition, this highly carbonaceous char has been applied as a catalyst in tar decomposition, corncob hydrolysis, and pyrolysis of waste engine oil (Kastner et al., 2015; Lam et al., 2015, 2016a; Shen et al., 2014).

According to Malaysia Palm Oil Board (MPOB), approximately 35 million tonnes of crude palm oil was produced in 2016 that resulted in the release of 6 million tonnes of palm oil mill effluent (POME) to the environment. POME is a harmful environmental pollutant due to its high levels of biochemical oxygen demand (BOD), chemical oxygen demand (COD), oil content and total solid (i.e. volatile solid and suspended solid). In addition, POME could release potentially hazardous compounds such as ammonia, sulphur dioxide, and halogens that have negative impacts on aquatic life if the untreated POME is dumped directly into the water (Igwe and Onyegbado, 2007). Hence, POME should be treated effectively to prevent environmental pollution.

The findings above provide the motivation for this study, which was to assess the potential of using biochar produced from pyrolysis of fruit peel to treat POME. Banana and orange peels that are abundantly and readily available in Malaysia were selected for this study. The peels were pyrolyzed over a range of temperatures (300–500 °C) in order to examine the product distribution with emphasis on the yield and composition of the biochar generated from the pyrolysis process. The biochar was then examined for its performance as adsorbent in the treatment of POME. There have been studies on treatment of POME by fermentation (Mamimin et al., 2015) and anaerobic digestion (Harsono et al., 2014). However, there has yet to be any study reported on the use of fruit peel biochar as adsorbent in the treatment of POME. Therefore, this study demonstrates a promising alternative to divert agriculture waste (i.e. fruit peels) from landfilling by transforming the waste into biochar to treat POME.

2. Materials and methods

2.1. Preparation and characterization of fruit peel

Two types of fruit peel were studied, namely banana peel (BP) and orange peel (OP). The fruit peels were collected from local fruit stalls in Kuala Terengganu, Terengganu, Malaysia. The peels were rinsed with tap water to remove dirt and sand particles. Next, the wastes were sun-dried to remove as-received moisture content. The pre-treatment was performed to ensure that the fruit peels were nearly representative of the 'real-world' peel waste sampled in dried form from the fruit industry. The dried peels were then cut into small pieces with a diameter of approximately 0.5–1.0 cm and stored before being subjected to characterization by chemical analysis and subsequent conversion into biochar by pyrolysis.

Elemental analysis was performed using a CHNS elemental analyser (FlashEA 1112) to analyse the elemental content of carbon, hydrogen, nitrogen, and sulphur present in the fruit peels; the oxygen content was obtained by the mass difference (i.e. $O = 100 - C - H - N - S$). The fruit peels were also analysed using a thermogravimetric analyser (TGA) (Mettler Toledo) by heating the sample inside the built-in horizontal furnace to determine the content of moisture and volatile matter. The moisture content was determined by the weight loss of the sample at 110 °C while the volatile matter was determined by the weight loss observed at temperature between 150 until 600 °C, whereas the ash content was obtained by combustion of the fruit peels in a muffle furnace at 950 °C with a holding time of 20 min. The fixed carbon content was then estimated by the mass difference (i.e. Fixed carbon = 100 − moisture − volatile matter − ash) (Lam et al., 2017b).

2.2. Pyrolysis of fruit peels

Pyrolysis of fruit peels was conducted in a pyrolysis apparatus consisting of a 120 mm diameter quartz reactor heated by a muffle furnace. The experiments were performed in a batch operation in which the production of biochar was targeted as the main pyrolysis product. 10 g of fruit peel was inserted into the reactor. Before the pyrolysis experiment was initiated, the reactor was purged with nitrogen gas for 5 min to expel oxygen from the reactor in order to create an inert environment for pyrolysis reaction to occur. The reactor was then sealed with stoppers and placed inside a muffle furnace in order for heating and pyrolysis to be performed. The reactor containing the fruit peel was then heated from room temperature to the desired pyrolysis temperature at a heating rate of 10 °C/min. Upon reaching the desired temperature, the fruit peels were pyrolyzed for 10 min. The pyrolysis experiments were conducted at different temperatures (300 °C, 400 °C, 500 °C) to examine the influence of temperature on the product distribution with an emphasis on the yield and composition of the solid char formed as a pyrolysis product (termed "biochar"). The experiments were conducted at a low heating rate ranging from 5 to 10 °C/min so that "slow" pyrolysis was performed (Uchimiya et al., 2011).

Pyrolysis volatiles were also generated and these volatiles remained inside the reactor during the pyrolysis process. The reactor was closely monitored to ensure that the pyrolysis volatiles did not drive out the stoppers due to the built up of the internal pressure. It had been ascertained from trial experiments that the internal pressure would not exceed such level at a pyrolysis temperature of $\leq$500 °C with the amount of fruit peel and N_2 gas inserted into the reactor. The reactor was removed from the furnace after the pyrolysis experiment. The biochar was collected while the