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# Improved yield and higher heating value of biochar from oil palm biomass at low retention time under self-sustained carbonization

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## ABSTRACT

Oil palm biochar with high yield and higher heating value under low energy requirement is required for improved waste management and utilization in the palm oil industry. This paper presents, a self-sustained carbonization of oil palm empty fruit bunch biomass, without internal heating element, which produced high biochar yield and higher heating value. Three different particle sizes of pressed-shredded oil palm empty fruit bunch biomass, i.e. below 29 mm, 30–99 mm and 100–150 mm, at 8–10% moisture content were used. The carbonization temperature was monitored and used as an indicator to stop the carbonization prior to harvesting. The maximum carbonization temperature recorded was 600 °C. In our previous report, harvested at 300 °C under uncontrolled exhausted air flow rate and found that the higher heating values obtained were 23.0–25.0 MJ/kg. However the biochar yield was only 14–16 %. In order to increase the yield of biochar, the exhaust air flow rate has been fixed at 36 $m^3$/hr by using an air suction blower to ensure uniform circulation and distribution of hot air from top to bottom before being discharged. The biochar was harvested when the temperature of the bed decreased to 500 °C. The particle size range from 100 to 150 mm produced the highest biochar yield of 26.0 ± 1.2% with higher heating value of 23.0–23.5 MJ/kg within 5–8 h retention time. The gaseous emissions were lower than permitted level set by the environmental authorities. The technology developed in this study should be used to improve the management and utilization of oil palm biomass towards a more sustainable palm oil industry.

## 1. Introduction

Biochar is attracting attention globally due to its unique potential for improved soil nutrient retention capacity, water holding capacity, increased crop yield and reduced greenhouse gas emissions (Kong et al., 2014). Zero-emission concept in the palm oil mill by using biochar for effluent treatment is attractive since biochar itself is non-chemical and the biomass is easily available within the palm oil industry (Othman et al., 2014). In addition, the use of biochar for heat and power generation has become more important due to the rapid depletion of fossil fuel. Production of biochar from oil palm biomass is gaining attention for improved waste management and utilization into value-added product (Kong et al., 2014).

Being the second largest oil palm producer in the world, Malaysia has enormous amount of oil palm biomass to produce biochar. Currently, there are 434 palm oil mills, producing an estimated 21 million tonnes of biomass residues annually in the form of oil palm empty fruit bunch (OPEFB), mesocarp fiber and palm kernel shell (MPOB, 2013; Talib et al., 2014). For each tonne of palm oil extracted, about 4 tonne of dry biomass is generated, of

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which a third is available at the mill in the form of empty fruit bunch (OPEFB), palm kernel shell (PKS) and mesocarp fiber (MF) which are the residues from the fresh fruit bunch (FFB) (Sulaiman et al., 2011). Approximately 23% OPEFB alone is produced per tonne of fresh fruit bunch daily in the mills, at no additional cost for collection (Omar et al., 2011). In some mills, OPEFB are subjected to size reduction, such as pressing and shredding to recover oil and to reduce the bulkiness for easier transportation.

Currently, mesocarp fiber and palm kernel shell are used as in-house fuel to generate steam and energy for palm oil mills' requirement, while raw OPEFB is partly sold for mulching purpose (Yusoff, 2006). The utilization of OPEFB to produce biochar for fuel can improve the waste management and create a new business opportunity for the palm oil industry. Biochar production operated nearby the mill using pressed-shredded OPEFB can help reduce the transportation cost and this allows it to be produced at a lower cost. Hence, biochar produced can be sold as a new value-added product especially for fuel based on higher heating value and operating cost. The mesocarp fiber and palm kernel shell can still be used as in-house fuel to generate steam, without involving any major changes in the oil palm mill operation. However, high capital investment and high energy requirement especially for large scale production to convert this biomass into biochar with high yield and higher heating value biochar were the main obstacles (Idris et al., 2015). Therefore, an appropriate technology with reasonable cost and energy requirement, without compromising on the yield and quality of biochar produced, could overcome this problem.

The carbonization process with low temperature and low heating rate is an appropriate technology for biochar production (Demirbas, 2004). Higher heating value (HHV) and high yield are positively correlated with carbonization temperature (Hooi et al., 2009; Ronsse et al., 2013) as well as retention time, heating rate and material size (Abdullah and Sulaiman, 2013; Hooi et al., 2009; Sugumaran and Seshadri., 2009; Sukiran et al., 2011). Self-sustained carbonization to produce biochar using biomass feedstock without an internal electrical heating is unique due to its simplicity, ease of operation and reduced energy requirement (Idris et al., 2015).

Under self-sustained carbonization of OPEFB with uncontrolled exhausted air flow rate, comparable HHV biochar between 17 and 25 MJ/kg can be obtained at harvesting temperature of 300 °C (Idris et al., 2015). However, the yield of biochar was less than 16%. In this study, self-sustained carbonization at fixed exhausted air flow rate and harvesting temperature of 500 °C to produce high biochar yield with comparable HHV was conducted, for improved waste management and utilization of oil palm biomass to be implemented in the oil palm industry.

## 2. Materials and methods

### 2.1. Sample preparation

Pressed-shredded OPEFB was obtained and prepared according to Idris et al. (2015). The HHV values of raw OPEFB and biochar were analyzed three to five times from samples at five different locations in the reactor using a Parr 1261 bomb calorimeter. Three different particle sizes of below 29 mm, 30–99 mm and 100–150 mm OPEFB biomass were used in this study. The gaseous pollutants ($CO_x$, $NO_x$, $SO_x$, HCl and $CH_4$) and particulate matter below 10 mm ($PM_{10}$) were measured according to Idris et al. (2015) using a gas analyzer (MRU Vario Plus, Germany) and $PM_{10}$ analyzer respectively.

### 2.2. Experimental setup

The detailed pilot-scale brick carbonization reactor specifications and carbonization operation procedure can be found in our previous study (Idris et al., 2015). However, the reactor was modified by installation of air suction blower to ensure the uniform circulation of hot air in the reactor from top to the bottom (Fig. 1). The exhausted gas flow rate discharged from the reactor was 36 $m^3$/hr. Once the carbonization commenced, valve 1 was set in open mode with valve 2 in closed mode. In this study, the harvesting temperature was used as an indicator to stop the carbonization process. OPEFB biochar was harvested when thermocouple 3 (T3) decreased to 500 °C and cooled down using sprayed water.

### 2.3. Analytical methods

A standard analytical test was done on the raw OPEFB and OPEFB biochar to determine moisture and volatile matter in the OPEFB samples. The thermal characteristics of dry OPEFB samples were analyzed with a computerized Perkin–Elmer Pyris 1 Thermogravimetric Analyzer and the ash content was determined following the standard method described by Nordin et al. (2013). The fixed carbon content was calculated by obtaining the difference. The ultimate analyses of Carbon (C), Hydrogen (H) and Nitrogen (N) content in OPEFB were determined using the CHNS/O Analyser (LECO CHNS932, USA) (Idris et al., 2013). The oxygen content was calculated by obtaining the difference. The chemical structure analysis (cellulose, hemicellulose and lignin content) in the OPEFB sample was analyzed via acid detergent fiber (ADF), neutral detergent fiber (NDF) and acid detergent lignin (ADL) methods analyses described by Omar et al. (2011). The HHVs of raw OPEFB and biochar were determined using a Parr 1261 bomb calorimeter (No. 242M).

## 3. Results and discussion

### 3.1. Characteristic of raw OPEFB biomass

The results of the proximate, ultimate, lignocellulose content and HHVs of raw OPEFB are shown in Table 1. All values are within the literature range except for fixed carbon which was slightly higher.

### 3.2. The effect of particle size and retention time on biochar yield and HHV at 500 °C harvesting temperatures

The temperature profiles in this study for all particle sizes tested were similar to those reported by Idris et el. (2015). Each

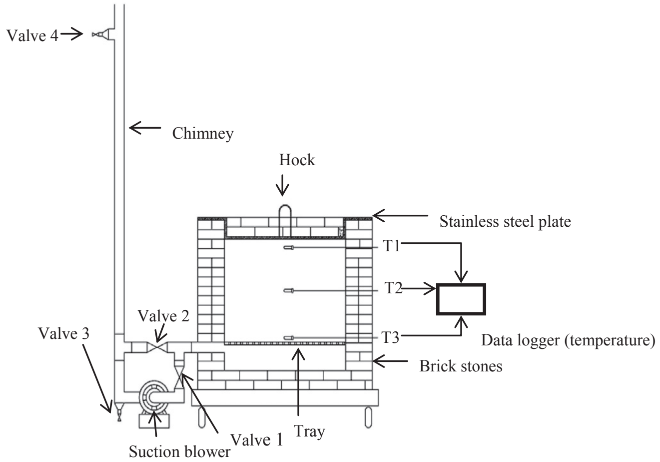

**Fig. 1.** Modified pilot scale self-sustained carbonization reactor with suction blower.

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