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Synthetic indicator on the severity of torrefaction of oil palm biomass residues through mass loss measurement

Khalik M. Sabil [a,*], Muafah A. Aziz [b], Bhajan Lal [a], Yoshimitsu Uemura [b]

[a] Phase Separation Laboratory, Research Centre of CO_2 Capture, Universiti Teknologi PETRONAS, Bandar Seri Iskandar, 31750 Tronoh, Perak, Malaysia
[b] Center of Biofuel and Biochemical, Chemical Engineering Department, Universiti Teknologi PETRONAS, Bandar Seri Iskandar, 31750 Tronoh, Perak, Malaysia

HIGHLIGHTS

- Mass loss is an excellent indicator of the severity of torrefaction has been proposed.
- Investigate the influence of torrefaction on the physiochemical properties of EFB, PMF and PKS.
- Calorific value and elemental analysis performed to study physicochemical properties.
- Mass loss, mass yield, energy yields, CHNS content, O/C ratio, calorific value is studied.

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ABSTRACT

In this work, the change of properties of empty fruit bunches (EFB), mesocarp fiber (PMF) and kernel shell (PKS) of oil palm when subjected to torrefaction process is reported. The properties include CHNS content, gross calorific value (GCV), mass and energy yields. These oil palm residues are torrefied at 200, 220 and 240, 260, 280 and 300 °C, respectively for duration of 2 h. In general, it has been found that the GCV and carbon content increase with the increase of torrefaction temperature but the O/C ratio, H and O content decrease for all residues. Also, we have shown that there are linear relationships between the mass loss with GCV and C content suggesting that it can be used as an indicator to monitor the severity of torrefaction process on these oil palm residues.

1. Introduction

The importance of bioenergy to ensure continuous sustainable energy supply has been widely recognized. Biomass energy is a good alternative to replace fossil energy as it has the ability to mitigate greenhouse effects, pollutant emissions as well as climate change [1–3]. In general, biomass residues as renewable energy sources have been widely studied as they are abundant, low cost, CO_2 neutral and content negligible amount of (S) sulphur and (N) nitrogen [4–9]. In a broader context, biomass can be described as solar energy stored in the form of chemical energy through chemical bonding of (O) oxygen, (C) carbon, and (H) hydrogen atoms [7]. When biomass is burned, the energy stored is converted into thermal energy and CO_2 is released into the atmosphere. The released CO_2 will be recaptured by the regrowth of the green plants through photosynthesis. Thus, biomass energy has been considered as a carbon–neutral fuel through this bio-cycle of carbon between the biomass and atmosphere [4,8,10].

According to the statistics of International Energy Agency (IEA) in 2005, biomass and its residues accounted for 10 of primary energy demand worldwide [6,9]. Unfortunately, in Malaysia, only 0.5 of the required energy demand came from renewable sources whereas about 93 of energy consumption was generated from the fossil fuel for the same period [2]. According to the rapid increase in energy demand in Malaysia, which is expected to reach 100 Mtoe (million tonnes of oil equivalent) in 2030, new alternative must be found in order to reduce the dependency on fossil fuels. Owing to this fact and the fluctuation price of fossil fuels, the government has targeted the renewable energy as the fifth fuel after oil, gas, hydro and coal, initiated under the Third Outline Perspective Plan (OPP3) for a 10 years period (2001–2010) [11] and Eight Malaysian Plan from 2001 to 2005 [12]. Since Malaysia is one of the largest producers of palm oil, a lot of oil palm residues are generated from the industry through replantation, harvesting

* Corresponding author. Tel.: +60 53687683 (O), +60 124211974 (HP); fax: +60 53755670.
E-mail address: khalik_msabil@petronas.com.my (K.M. Sabil).

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and processing of the oil palm. In 2009, it has been estimated that 17.08 MnT/year of empty fruit bunch (EFB), 12.9 MnT/year of frond, 9.66 MnT/year of palm mesocarp fiber (PMF) and 5.2 MnT/year of palm kernel shell (PKS) have been generated as residues from this industry [3]. Due to this fact, oil palm residues seem to have great potentials to become an alternative source of energy for the country.

However, it is quite challenging for direct utilization of oil palm residues as feedstock for fuel production such as gasification or pyrolysis. Most of the palm plantations and their processing plants are located in rural areas. Due to the distance and high moisture content of oil palm residues, the raw materials are exposed to fungal attack and biodegradation during storage and transportation [5,10,13]. The high moisture content which can reach as high as 60% of for certain residues also can complicate the combustion process for energy production if use untreated since a lot of liquid will be generated from the process [5,9–11]. Moreover, these residues also have relatively low calorific value, high O/C ratio and energy density [4,9,13]. Tenacious and fibrous nature of these residues also leads to poor grindability [9,10,13]. Additionally, a very high load of biomass is required to generate equivalent amount of energy when compared to fossil fuel such as coal [10]. To overcome these drawbacks, pretreatment of these residues is necessary and torrefaction process is the one of the viable option to be used.

Torrefaction is a thermal pre-treatment process for biomass at temperature range of 200–300 °C in an inert atmosphere [4–6,8–14]. This process modifies the physiochemical properties of biomass and drastically reduces the amount of moisture in the biomass. Generally, torrefaction degrades mostly hemicellulose fraction of the biomass, whereas the degradation extents of cellulose and lignin is strongly depended on the torrefaction temperature [6,9]. During the process, light volatiles are released and carbonization reaction takes which increase the heating value of the torrefied biomass. [6]. The advantages of torrefied biomass over raw biomass include lower moisture content, higher C content and lower O/C ratio. All these alterations lead to prolong the storage duration of the treated biomass, increase its heating value, improve its grindability and increase its reactivity during combustion or gasification process [4–6,9,10,13].

In literature, experimental torrefaction studies are mostly reported for woody and grass biomass including wood dusts [14] beech [15–17], eucalyptus [10], willow [13,15,16,18], larch [15,16], and canary grass [13]. In addition, torrefaction of agricultural lignocellulosic residues, such as wheat straw [15,16,13] are discussed in few literatures. Most of the findings show improvements of physical and chemical properties of the biomass when subjected to torrefaction including grindability [10], fuel quality [5] and feedstock quality [6,7] of the studied biomass. In addition, Prins et al. proposed a kinetic model of torrefaction [15], and reported the details of torrefaction mass balance [16]. Moreover, Uslu et al. have reported on the comparison of torrefaction, fast pyrolysis and pelletization from the viewpoint of the international bioenergy logistics [14]. Most interestingly, Almeida et al. has recently shown that the mass loss is a good indicator on the severity of the torrefaction of eucalyptus wood and bark [19].

Although a number of studies have been performed on torrefaction of agricultural residues, less attention had been paid on torrefaction of oil palm residues. In literature, only Uemura et al. has discussed in details the torrefaction of empty fruit bunches (EFB), palm mesocarp fiber (PMF) and palm kernel shell (PKS) [20]. However, their study is based on torrefaction of these residues for a period of 30 min. In our opinion, the torrefaction process reported in this work does not go until completion in the stipulated duration. Since torrefaction is a time dependent process, the quality of the torrefied products, mass and energy yields is greatly affected by the period of torrefaction. Moreover, the origin of the biomass residues must be taken into consideration because the chemical and physical properties of these residues are dependent on the location of which their trees are planted. Taking into consideration of the limited data on torrefaction of palm oil residues, this study is conducted by using oil palm residues collected for different location that that is reported by Uemura et al. [20]. The main objective of this study is to investigate the change in properties of oil palm residues subjected to prolong torrefaction process of 2 h. Also, this study is conducted to determine if the mass loss is a good indicator on the severity of torrefaction process on palm oil residues as it is for eucalyptus wood and bark [19]. The main emphasis has been given to the mass loss as an indicator of torrefaction severity, elemental composition, mass and energy yields.

2. Experimental

2.1. Materials

In this study, EFB, PMF and PKS of fresh fruit bunch (FFB) of oil palm (*E. guineensis*) are tested. These three types of oil palm residues are collected from FELCRA Nasaruddin plantation located in Bota, Perak (4° 21′ 10.50″ North, 100° 54′ 20.33″ East) Malaysia. Several operational units are involved during the separation of EFB, PMF and PKS from FFB of oil palm once they are transported to the oil palm mill. After stripping off all fruit-lets from the sterilized fresh fruit bunches during milling process, EFB is produced as the by-product. PKS is produced after cracking of nuts and extraction while PMF is extracted after oil extraction and nuts separation. All the materials are oven dried at 105 °C for 24 h. Then, the raw materials are grinded and sieved into two particle size ranges of 250–355 μm and 355–500 μm before being stored in air-tight container and used without any pre-treatment.

2.2. Torrefaction process

A tube furnace, model TSH17/75/450-2416-2116, manufactured by Elite Thermal Systems Limited is used for torrefaction process. Nitrogen gas flow and heating rate are fixed at 100 ml $min^{-1}$and at 10 °C/min, respectively. For each measurement, approximately 2 g of sample is placed in the furnace. A temperature programme consisted of a dynamic heating period and an isothermal heating period is used to control the torrefaction process. Specifically, the temperature is raised from room temperature to 50 °C and the heating continued until it reached to 120 °C. Then, the temperature is held for 10 min. Next, the temperature is raised from 120 °C until it reached the desired value of 220, 260 and 300 °C, respectively. Once the tube furnace reached to the final torrefaction temperature, the sample is continuously torrefied for two hours.

2.3. Elemental analysis (CHNS) and calorific value determination

Elemental analysis is conducted to measure the C, H, N and S content in the untreated and torrefied biomass. The LECO CHNS elemental analyser is operated with constant helium flow at 1000 °C. For each measurement, approximately 2 mg of sample is used. Meanwhile, the calorific value is measured by using IKA-WERKE C5000 bomb calorimeter. The sample is weighed and placed into plastic crucible and tied with cotton twist attached to the bomb. The measured calorific value is the high heat value (HHV) which includes the heat of condensation of water vapor produced in the combustion.