PREPARATION OF BIOCOKE FROM PALM OIL RESIDUE

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Abstract

Biocoke is a bio-solid fuel which is produced from biomass resources such as waste from agro-processing industry. Biocoke is expected to use as a co-fuel with coke and coal for cupola furnace in metal-casting industry and boiler. The expected properties of biocoke for industrial use should have the following properties: 1) density is higher than 1.1 g/cm^3, 2) maximum compressive strength is higher than 20 MPa and 3) calorific value is higher than 4,000 kcal/kg. In this research, biocoke was prepared from palm oil residue at different forming time (10, 15, 20, and 25 min). The forming temperature and forming pressure were, respectively, fixed at 180°C and 16 MPa. The density and maximum compressive strength of the prepared biocokes slightly increase with the increase of forming time. In addition, the calorific value of biocoke significantly increases when the forming time is increased from 10 min to 15 min. However, the increase in forming time longer than 15 min has no effect on the calorific value of biocoke from palm oil residues.

Keywords: **Bio-solid fuel, biocoke, biomass, palm oil residue, renewable energy**

Introduction

In 2017, Thailand has become the world's third largest area for plantation palm. The plantation area of palm was approximately 8,500 km^2 and the production of palm was 13.5 million ton/year which were extract to 25 million ton/year of palm oil (Chuasuwan, 2018). Large amount of palm oil residues are generated from palm oil milling industry. Previously, palm oil residues from palm oil industry are expected to use as animal feeding. However, palm oil residues are not suitable to use as animal feeding because of the low protein content and high fiber content in palm oil residues (Yunilas *et al*., 2014). The alternative utilization of palm oil residues as bio-fuel is considered. Palm oil residues are composed of lignin, cellulose and

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hemicellulose (Hamzah *et al*., 2019). Therefore, the palm oil residues have a potential to develop as bio-solid fuel such as biocoke.

Biocoke is a bio-solid fuel which is produced from biomass resources such as waste from agro-processing industry (Ida *et al*., 2014). Biocoke is expected to use as a co-fuel with coke and coal for cupola furnace in metal casting industry and boiler (Ishii *et al*., 2009). However, the physical and thermal properties of biocoke such as density, maximum compressive strength and calorific value are needed to improve to meet the requirement of industrial utilization (Mizuho Information and Research Institute, 2015). The expected properties of biocoke for industrial use should have the following properties: 1) density is higher than 1.1 g/cm^3, 2) maximum compressive strength is higher than 20 MPa and 3) calorific value is higher than 4,000 kcal/kg. It has been reported that the properties of bio-solid fuel e.g., biocoke and briquette, depend on type and composition of raw materials (Coates, 2000; Murata, Hanaka *et al*., 2014; Chaichanawong, 2017; Chaichanawong, 2018), binders (Chou *et al*., 2009; Murata, Yoshikuni *et al*., 2014; Zhang *et al*., 2018 Aransiola *et al*., 2019), particle size of raw material (Cherdkeattikul *et al*., 2015) and forming condition such as forming temperature, forming pressure, forming time and moisture content (Sawai *et al*., 2010; Ida *et al*., 2013; Chaichanawong *et al*., 2015; Cherdkeattikul *et al*., 2015; Saisermsak *et al*., 2015; Kawamura *et al*., 2018; Nurek *et al*., 2019).

In this research, biocoke was prepared from palm oil residue which is the waste form palm oil milling process. The effect of experimental condition on properties of the prepared biocokes, i.e., density, compressive strength and calorific value were investigated. The obtained results could suggest the best conditions for the preparation of biocoke from palm oil residue for industrial use.

Materials and Methods

Preparation of Raw Material

In this study, the palm oil residues from the same palm oil production factory were used as the raw material for preparation of biocoke. Figure 1 shows photo of palm oil residue which was used for preparation of biocoke. The lignocellulosic compositions of palm oil residues were evaluated by using Van Soest method (Van Soest *et al*., 1991). The lignocellulose compositions (hemicellulose, cellulose and lignin contents) of palm oil residues are summarized in Table 1. The palm oil residue used in this study consists of 11.27 wt% of lignin, 27.19 wt% of cellulose, 24.98 wt% of hemicellulose and 35.56 wt% of others. This result confirmed that it is possible to prepare the biocoke from palm oil residues. The particle sizes of palm oil residues were classified by using sieve shaker. The palm oil residues with the particle sizes smaller than 1 mm were chosen for preparation of biocoke. The moisture of palm oil residues was

Figure 1. Photos of palm oil residue for preparation of biocoke

Table 1. Lignocellulosic compositions of palm oil residues

Raw material	Compositions (wt%)			
	Lignin	Cellulose	Hemicellulose	Others
Palm oil residues	11.27	27.19	24.98	35.56

controlled at 10 wt% by using electric oven at 110°C.

Preparation of Biocoke

Figure 2 shows the photo of the apparatus for preparation of biocoke from palm oil residues. The apparatus consists of the hydraulic piston and a vertical-cylindrical reactor with 50 mm of the inner diameter covered with electrical heater. 50 g of palm oil residues were fed in to the vertical-cylindrical reactor. Then, the palm oil residues in the vertical-cylindrical reactor were pressed under controlled pressure at 16 MP in all experiments. The forming temperature was set at 180°C. To investigate the effect of forming time, the forming times were set at 10, 15, 20, and 25 min. After reaching the setting the forming time, the vertical-cylindrical reactor was cooled down to room temperature. Then, the prepared biocoke was discharged from the vertical-cylindrical reactor.

Figure 2. Photo of the apparatus for preparation of biocoke

Evaluation of Biocoke Properties

As mentioned in section 1, the expected properties of biocoke for industrial use should have the following properties: 1) density is higher than 1.1 g/cm^3, 2) maximum compressive strength is higher than 20 MPa and 3) calorific value is higher than 4,000 kcal/kg. Therefore, these three properties the prepared biocokes at different forming time were evaluated by the following methods.

The density of biocoke was estimated by Equation (1).

$$D = m / V \quad (1)$$

where D is the density of the prepared biocokes (g/cm^3), m is weight of the prepared biocoke (g), V is volume of the prepared biocokes (cm^3).

The maximum compressive strength of the prepared biocokes was measured by the compression testing machine (Shimadzu, UH-1000kNXR) and estimated by Equation (2).

$$\sigma_{max} = F_{max} / A \quad (2)$$

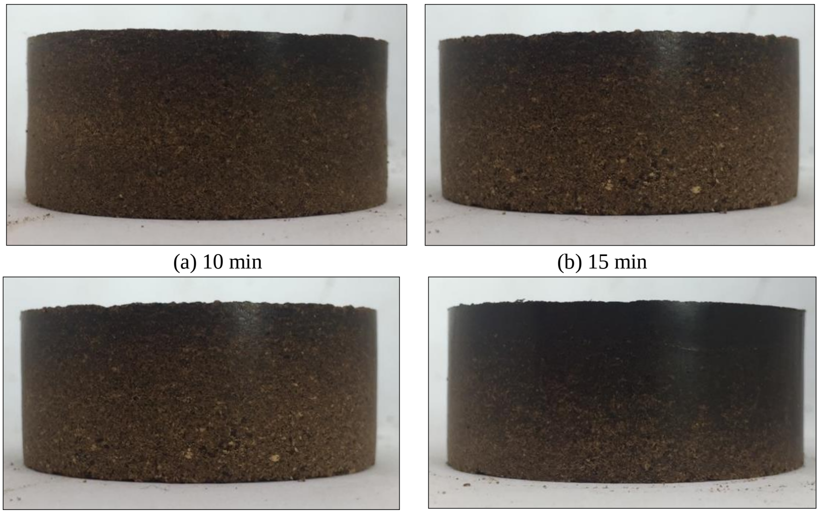
where σ_{max} is maximum compressive strength of the prepared biocokes (MPa), F_{max} is maximum compressive force which the prepared biocokes was obtained (N) and A is cross section area of the prepared biocokes (m^2). The calorific value of the prepared biocokes was measured by the bomb calorimeter (IKA, Model C1).

The microstructure analysis of the fracture surface of the prepared biocoke was conducted by using scanning electron microscopy (SEM, Hitachi S-4800) to observe the change in microstructure of the biocoke at different forming time.

Results and Discussion

Figure 3 shows the side-view photos of the prepared biocokes from palm oil residues. The color of biocokes from palm oil residues are brown and the color of the biocoke becomes darker at longer forming time. This is because of the higher degree of decomposition of main compositions in palm oil residues such as hemicellulose (Mobarak *et al.*, 1982; Takahashi, 2010) at longer forming time.

Figures 4 and 5 show the influence of forming time on the density and maximum compressive strength of the prepared biocoke from palm oil residues. The density and



(a) 10 min (b) 15 min

(c) 20 min (d) 25 min

Figure 3. The side-view photos of biocoke from palm oil residues at different forming time

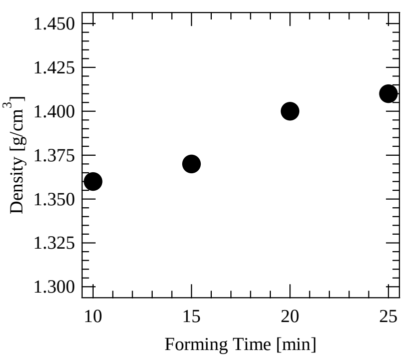


Figure 4. Influence of forming time on density of biocoke from palm oil residues

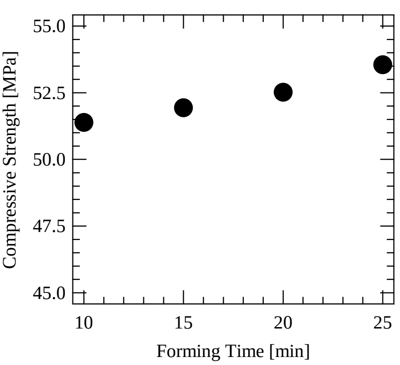
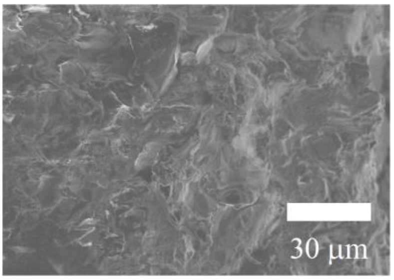


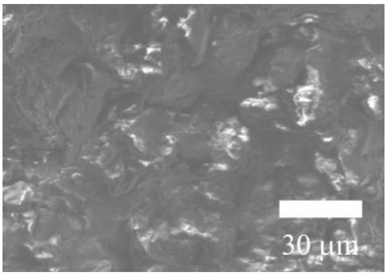
Figure 5. Influence of forming time on the compressive strength of biocoke from palm oil residues

maximum compressive strength of the prepared biocokes slightly increase with the increase of forming time. The softening of hemicellulose in palm oil residues, which has adhesive properties (Kaliyan and Morey, 2010; Cherdkeattikul and Ida, 2019; Kanada *et al*., 2019), at longer forming time at this preparation temperature is considered as the key factor on the increase of density and compressive strength. The SEM images of the fracture of the biocokes which is prepared at 10 min and 20 min are shown in Figure 6. It is confirmed that the biocoke which is prepared at longer forming time leads to the denser microstructure. The values of density and maximum compressive strength of the prepared biocokes at these forming time (10, 15, 20, and 25 min) are higher than the expected properties of biocoke for industrial utilization.

Figure 7 shows the influence of forming time on the calorific value of the prepared biocoke from palm oil residues. It is found that the calorific value of biocoke significantly increases when the forming time is increased from 10 min to 15 min. However, there is no



(a) 10 min



(b) 20 min

Figure 6. SEM image of fracture surface of the biocokes from palm oil residues

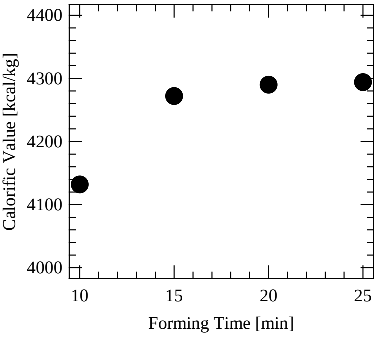


Figure 7. Influence of forming time on the calorific value of biocoke from palm oil residues

significant change when forming time are increased from 15-25 min. It is confirmed that the forming time at 15 min is enough for the preparation of biocoke from palm oil residues at 180ºC and 16 MPa. The increase in forming time longer than 15 min has no effect on the calorific value of biocoke from palm oil residues.

The maximum density, compressive strength and calorific value of the biocoke from palm oil residues were, respectively, 1.4 g/cm^3, 53.5 MPa and 4,294 kcal/kg which was obtained by forming at 180ºC, 16 MPa for 25 min. It is confirmed that the biocoke from palm oil residues has a potential to use as co-fuel with coal and coal coke in iron-smelting and metal-casting industry because their density, maximum compressive strength and calorific value are higher than 1.2 g/cm^3, 20 MPa and 4,000 kcal/kg, respectively. In terms of the energy used in the process, the estimated electricity consumption for the production of biocoke are 1.46 kWh/kg of biocoke (Fuchigami *et al*., 2016) whereas the energy gain from the prepared biocoke in this research are equivalent to 4.99 kWh/kg of biocoke. However, the influence of other preparation condition such as forming temperature, forming pressure and mixing ratio of raw materials would be studied further to optimize the preparation condition for industrial production.

Conclusions

Biocoke was prepared from palm oil residues. The influence of forming time on the properties of biocoke was investigated. The density and maximum compressive strength of the prepared biocokes slightly increase with the increase of forming time. In addition, the calorific value of biocoke significantly increases when the forming time is increased from 10 min to 15 min. However, The increase in forming time longer than 15 min has no effect on the calorific value of biocoke from palm oil residues. The maximum density, compressive strength and calorific value of the biocoke from palm oil residues were, respectively, 1.4 g/cm^3, 53.5 MPa and 4,294 kcal/kg which was obtained by forming at 180ºC, 16 MPa for 25 min. It is confirmed that the biocoke from palm oil residues has a potential to use as co-fuel with coal and coal coke in iron-smelting and metal-casting industry.

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