Effect of forming temperature on properties of biocoke from palm oil residues

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Abstract. Biocoke is a solid fuel produced from bio-residues such as agricultural residues. Biocoke is expected to use as a replacement for coal coke to reduce CO₂ and pollution gases emission. In this research, biocoke was developed from palm oil residue which is one of the main wastes from palm oil industry. The effects of forming temperature on properties of the biocoke such as bulk density, maximum compressive strength and calorific value were investigated. Biocoke from palm oil residue was produced at different forming temperatures (from 140 °C to 190 °C). The forming time was fixed at 20 min. The forming pressure was also fixed at 16 MPa. The bulk density and calorific value of biocoke from palm residue increase with the increase of forming temperature. However, maximum compressive strength of biocoke from palm residue decreases with the increase of forming temperature. However, maximum compressive strength of biocoke from palm residue decreases with the increase of forming temperature.

Keywords: Biocoke, Bio-solid Fuel, Alternative Energy, Renewable Energy, Palm oil residues.

1. Introduction
The increasing demand on the use of fossil fuel as an energy source lead to economic and environmental issues of concern. In addition, the use of fossil fuel is the major source of greenhouse gases and pollution gases emission. Hence, the development of efficient technologies for generation of renewable energy to reduce the use of fossil fuel is necessary. Biocoke is a solid fuel produced from bio-residues such as agricultural residues. Biocoke is expected to use as a replacement for coal coke in the iron and steel foundry industry to reduce pollution gases emission. However, it is necessary to improve the physical and thermal properties of biocoke to meet the requirement of the iron and steel foundry industry such as high bulk density, compressive strength and calorific value. It has been reported that types of raw materials, forming temperature, forming pressure and forming time are important factors that effect on physical and thermal properties of biocoke [1-8].

Recently, Thailand has become one of the world leaders for palm oil production. Palm seed has been used for extraction to palm oil. Palm oil residues produce a large quantity of biomass. Palm oil residue is one of the main wastes from palm oil industry. Palm oil residues from palm oil industry are usually used as animal feed. However, there are limitation factors for utilization of palm oil residue as animal feeding such as low protein content and high fiber content [9]. The palm oil residues are cellulosic material which are mainly consisted of cellulose, hemicellulose and lignin [10]. Therefore, the palm oil residues have a potential to develop as alternative energy such as biocoke. In this research, biocoke was produced from palm oil residue at different forming temperatures. The effect of forming temperature on properties of the biocoke such as bulk density, maximum compressive strength and calorific value were investigated.
2. Experimental

2.1 Production of Biocoke

The production of biocoke was carried out by a vertical-type biocoke pressing machine as shown in Figure 1. The inside diameter of cylindrical reactor was 50 mm. The palm residues with particle size smaller than 1 mm were used as raw material for the production of biocoke. The palm residues were dried at 110 °C in oven to control their moisture content to 10 wt%. Then, 50 g of the prepared palm residues were loaded into the vertical type biocoke pressing machine. To investigate the effect of forming temperature on properties of biocoke, the forming temperature was varied from 140 to 190 °C whereas the forming time was fixed at 20 min. The forming pressure was set at 16 MPa for all experiments. Finally, the obtained biocoke was cooled down and discharged from the vertical-type biocoke pressing machine.

![Figure 1. Photo of the apparatus used for production of biocoke.](image)

2.2 Analysis of Biocoke Properties

Bulk density, maximum compressive strength, and calorific value are important properties of the biocoke for using as a co-fuel with coal coke in the iron and steel foundry industry. In this study, the expected properties of bulk density, compressive strength and calorific value are higher than 1.2 g/cm³, 20 MPa and 4,000 kcal/kg, respectively. To investigate the effect of forming temperature on the properties of biocoke, bulk density, maximum compressive strength and calorific value of the biocoke from palm oil residues were evaluated using the following methods.

2.2.1 Bulk Density.

Bulk density of biocoke was calculated by equation (1).

\[ D_B = \frac{m}{V} \]  

Where \( D_B \) is the bulk density (g/cm³), \( m \) is mass of biocoke (g) and \( V \) is volume of biocoke (cm³).

2.2.2 Maximum Compressive strength.

To utilize the biocoke in iron and steel foundry industry, high maximum compressive strength is required to support load in the furnace. The maximum compressive force that the biocoke can be obtained was measured using the universal testing machines (Shimadzu, UH-1000kNXR) and estimated by using equation (2).

\[ \sigma_{max} = \frac{F_{max}}{A_0} \]  

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where is \( \sigma_{\text{max}} \) maximum compressive strength of biocoke (MPa), \( F_{\text{max}} \) is maximum compressive force that biocoke can be obtained (N) and \( A_0 \) is the cross section area of biocoke (m\(^2\)).

### 2.2.3 Calorific Value

The calorific value of the biocoke was determined using the bomb calorimeter (IKA, Model C1).

### 3. Results and discussion

Figure 2 shows the photos of the example of biocoke from palm oil residues. The color of biocokes from palm oil residues became darker at higher forming temperature. In addition the small crack are observed at the top surface of the biocoke which produced at 180 °C and 190 °C.

![Figure 2](image)

Figure 2. The top-view photos of biocoke from palm oil residues at different forming temperature.

Figure 3 - 5 show the effect of forming temperature and bulk density, maximum compressive strength and calorific value of the biocoke from palm oil residues, respectively. The bulk density and calorific value of the biocoke from palm oil residues gradually increase with the increase of forming temperature. The thermal decomposition of hemicellulose in raw materials at higher forming temperature is considered as the key factor on the increase of bulk density [11] and calorific value. In contrast, the maximum compressive strength of the biocoke from palm oil residues significantly decreases with the increase of forming temperature from 140 – 180 °C. However, the maximum compressive strength of the biocoke from palm oil residues which were produced at 180 °C and 190 °C are almost similar. This is because the small cracks which are observed in the biocoke from palm oil residues at 170 °C and 190 °C.
Figure 3. Effect of forming temperature on bulk density of biocoke from palm oil residues.

Figure 4. Effect of forming temperature on the maximum compressive strength of biocoke from palm oil residues.
4. Summary

The effect of forming temperature on properties of the biocoke from palm oil residues such as bulk density, maximum compressive strength and calorific value were investigated. Biocoke from palm oil residue was produced at different forming temperatures (from 140 to 190 °C). The bulk density and calorific value of biocoke from palm residue increase with the increase of forming temperature. In contrast, maximum compressive strength of biocoke from palm residue decreases with the increase of forming temperature due to the small cracks at higher forming temperature. The effect of other factors such as forming time and forming pressure on the properties of biocoke from palm oil residue would be considered in the future works.

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