Thermogravimetric Analysis of Densified Coco Peat Briquettes

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Abstract. The present work deals with the investigation of thermal decomposition of densified coco peat briquettes using the thermogravimetry method to elucidate the effect of finite size of the biomass briquette on the decomposition profile. The cylindrical samples are varied in term of its density and its shape (sphericity). The sample is heated in a nitrogen atmosphere at different heating rates, ranging from 5°C/min to 20°C/min. The TG curves show three distinct phases of decomposition, i.e. preheating and drying, devolatilization, and char reduction. For all samples, thermal decomposition shifts to higher temperatures with the increase in the heating rate. From the TG curves, it is shown that the initial degradation temperature varies from 181°C to 302°C and the final degradation temperature varies from 328°C to 608°C. The shift to higher temperatures is also observed for the less dense briquettes. The shape of the briquettes affects also the decomposition profile. The less spherical (less of contact area) sample will decompose at higher temperatures. From the DTG curves, it can be seen that the maximum thermal degradation rate takes place at varying temperature ranging from 243°C to 419°C. The peak temperatures depend on the heating rate. However, the density and the shape of the biomass have no appreciable effect on the peak temperature.

Keywords: thermogravimetric, coco peat briquettes, biomass, decomposition

1. Introduction
Indonesia represents the world leader of coconut (Cocos nucifera L.) producer. It is estimated that the production reached around 2.9 million tons in 2018 [1]. Various products may be derived from the coconut fruit. The main product of coconut is copra (endosperm) which is widely utilised in both food and non-food industries. Apart from copra, coconut fruits also engender shells and husks. Shells can be used as raw material for activated carbon production and husks can be utilized for the production of floor covering, mats and matting, etc. Each coconut fruit yields about 35% by weight of husk [2]. The coconut husk consists of about 30% fibre and 70% coco peat or coco pith [3]. Coco peat constitutes commonly a by-product of coir fibre extraction. In Indonesia, the fibre extraction is mostly carried out by smallholders. It is often that coco peat is dumped on site. This poses serious disposal and environmental problems.

Coco peat has a high potential for renewable energy production. The utilization of coco peat for energy use will alleviate the problem of waste disposal and at the same time uphold the reduction of greenhouse gases by substituting to some extent fossil fuels. The potential as renewable energy feedstock is promising by the fact that coconut is a non-seasonal crop and, hence, its availability would be year-round.

Like majority of agricultural wastes, coco peat is commonly available in a loose packed form that engenders a problem of handling and transportation. Biomass pelletizing or briquetting could be adopted to cope with such kind of problem. Pelletizing or briquetting also increases the energy density of the
biomass. Physical and burning properties of pellets or briquettes made from coco peat are given in [4], [5]. Another method of preparing coco peat as energy feedstock is by converting it into biochar [4], [6].

A fundamental understanding of the thermal properties of the cocopeat is of importance in considering its use as fuel feedstock. Various thermal analysis techniques have been developed to characterize the thermal behaviour of biomass feedstock, such as direct scanning calorimetry, thermogravimetry analysis, mechanical thermal analysis. The detail description of thermal analysis techniques can be found elsewhere [7]. Thermogravimetric analysis (TGA) is the simplest one. This technique measures the mass of a sample in a controlled atmosphere as a function of temperature. The TGA can be used to analyse the thermal decomposition of substances, corrosion of metals, determination of moisture, volatiles and ash content, evaporation rates and sublimation, distillation and evaporation of liquids, reaction kinetics studies, compound identification, and heat vaporization and vapour pressure [8]. Olatunji et al. [9] also reported that the TGA has been applied to different studies, such as devolatilization, reaction region and kinetics, combustion, pyrolysis, gasification, and thermal decomposition. The study of biomass thermal decomposition by TG analysis has been also covered a wide range of different biomass feedstocks such as wooden biomass [10], [11], biomass-derived oil [12], [13], and marine biomass [14] to name a few. The information from thermogravimetric analysis can contribute to the understanding of pyrolysis reaction mechanism which is constructive in the process optimization or reactor design at industrial scale [15].

TGA analysis uses in general a sample of small size to prevent the bulk effect and thermal gradient developed within the sample. A knowledge of thermal characteristics of biomass feedstocks of finite size is equal importance in view of its utilization as a renewable energy resource. To the knowledge of the author, the thermogravimetric analysis of the biomass of finite size is still limited. The application of TGA to samples of finite size has been performed by Jiang et al. [16], among others. They investigate the effect of the polystyrene particle size on the reaction rate. The particle size ranges from 5 to 50 μm. They reported that size presented influence to the first and second steps reactions. The biomass fuel feedstock is generally available in the form of pellets or briquettes at larger sizes. The knowledge of the decomposition profile of such fuel feedstock is useful in the design of the reactor at industrial scale. The current study aims at characterizing thermal decomposition of cocopeat briquettes of finite size at this stage with different densities and shapes by using thermogravimetric analysis.

2. Experimental

2.1. Samples

The cocopeat sample was taken from a smallholder in West Sumatra, Indonesia. The structural composition of the cocopeat is given in Table 1. It can be seen from the Table 1 that the main constituent of the cocopeat is lignin; it counts more than 50%. Different briquette samples were prepared. The first were samples having the same dimension but differing in density (sample A and B). The second were samples having the same density but differing in shape or size (sample A and C). The dimension and density of samples used in the experiment are summarized in Table 2.

| Composition | Mass Fraction (%) |
|-------------|------------------|
| Hemicellulose | 9.40 |
| Cellulose    | 32.90 |
| Lignin       | 54.00 |
| Extractive   | 2.28 |

| Sample | Diameter (cm) | Height (cm) | Density (g/cm³) |
|--------|---------------|-------------|-----------------|
| A      | 4.0           | 2.0         | 1.3             |
2.2. Experimental set-up and procedure

The experimental set-up is schematically depicted in Figure 1. A programmable muffle furnace is used as reactor. A rigid lever bar is inserted through the furnace exhaust port that is located at the rear wall. The biomass sample dish is mounted on one end of the lever with the help of stainless wires. To record the change of the sample mass in the course of experiment, a tension/compression load cell was employed. The load cell was attached to the other extremity of the lever. An amplifier was connected to load cell with the objective of enhancing the signal output. Calibration of the load cell output was made by using pre-weighed masses. Four pre-weighed masses were selected such to correspond the biomass sample mass range in the experiment. A mathematical expression relating the load cell voltage outputs and the pre-weighed masses was established by employing a regression method.

Three levels of heating rate were selected during the run of experiment, namely 5, 10, and 20 °C/min. The nitrogen flow was kept small in purging air from the reactor chamber and maintaining the chamber atmosphere inert. The runs were concluded whenever the change in sample mass is indiscernible. Mass data recorded were smoothed using a moving average technique as described by Chen et al. Three levels of heating rate were selected during the run of experiment, namely 5, 10, and 20 °C/min. The nitrogen flow was kept small in purging air from the reactor chamber and maintaining the chamber atmosphere inert. The runs were concluded whenever the change in sample mass is indiscernible. Mass data recorded were smoothed using a moving average technique as described by Chen et al. [17]. For every data point, smoothing was made by averaging a span of 11 data points. A smaller number of data points was used for endpoints. The DTG curves were deduced from TG data by employing five-points numerical differentiation.

|   | 5°C/min | 10°C/min | 20°C/min |
|---|---------|----------|----------|
| B | 4.0     | 2.0      | 2.3      |
| C | 6.0     | 1.5      | 1.3      |

![Figure 1. Simplified schematic of experimental set-up](image)

3. Results and Discussion

3.1. Effects of heating rate

Figure 2 shows the TG and DTG curves for different heating rates. It can be seen from the figure that all samples show three discernible thermal degradation phases. However, at higher heating rates, the points of inflection are less obvious. For all samples, the higher heating rate shifts the decomposition to higher temperatures. It is to also note that the shift of temperature is even more notable. This is due the size of the sample. At higher heating rate, the surface of the sample is subject to excessive heating over the inner parts of the biomass and no sufficient time is available for every part of the biomass reaching thermal equilibrium. The outer layer will reach first the temperature required by volatiles for decomposition. At the same time, char with low thermal properties is formed at the outer surface which in turn impedes the heat diffusion towards inside of the biomass [18].

For the samples used in the experiment, the onset temperature varies between 181°C – 302°C, the completion temperatures from 328°C to 608°C and the peak temperatures from 243°C to 419°C. Table 3 summarizes the temperature degradation. Yang et al. [19] showed that hemicellulose decomposes mainly at 220°C – 315°C, cellulose at 315 °C – 400 °C, and lignin at wider range, i.e. 160 °C – 900 °C.
However, Panamgama & Peramune [20] indicated that thermal behaviour of lignin varies, depending on the chemical extraction protocols and energy supply modes.

![TG and DTG curves at different heating rates](image)

**Figure 2.** TG and DTG curves at different heating rates

DTG curves show shifts of peak temperatures to higher values with the increase in the heating rate. The thermal degradation rates also increase with the heating rate. A relatively linear increase in peak temperatures with respect to the heating rate is observed in the range of 5 – 20°C/min. However, such tendency should be verified for a greater range of the heating rate.

**Table 3.** Degradation temperatures

| Sample | Heating Rate (°C/min) | Onset Temperature (°C) | Completion Temperature (°C) | Peak Temperature (°C) |
|--------|-----------------------|------------------------|-----------------------------|-----------------------|
| A      | 5                     | 181                    | 328                         | 243                   |
|        | 10                    | 248                    | 407                         | 307                   |
|        | 20                    | 282                    | 503                         | 380                   |
3.2. Effects of density

Figure 3 shows TG and DTG curves of samples of different density. Figure 3 is extracted from Figure 2 with the objective to elucidate the effects of density to the decomposition profile. The figure compares the sample A and B. Both samples have the same dimension, but differ in density and hence differ in mass. Both TG and DTG curves are normalized to the initial mass, $m_0$. For all heating rates, the temperature of degradation shifts to higher temperature for the dense sample. Since the biomass has low thermal properties, the dense biomass will impart higher thermal resistance. From the DTG curves, it is seen that the absolute rate of degradation of the dense sample is superior over the less dense one, while the peak temperatures just differ to a lesser degree for all heating rates. This suggests that the density of the samples has less pronounced effect to the peak temperature than the heating rate does.

(a) Heating rate: 5°C/min

(b) Heating rate: 10°C/min
3.3. Effects of shape
Figure 4 compares the TG and DTG curves between the sample A and sample C. Both samples have the same density, but differ in dimension, and hence differ in both volume and mass. The shape of the sample is described by its sphericity; the sample A and C have sphericity of 0.83 and 0.69, respectively. A greater sphericity indicates a greater surface area per unit of volume. Figure 4 reveals that greater sphericity biomass sample tends to decompose at lower temperatures. The sample with greater sphericity has greater contact area that promotes higher heat exchange. This result is in an agreement with findings of various literature [21-22]. Xiao, et al. [23] also showed the same results in the pyrolysis of rice straw and pine sawdust, but an opposite result was found for the case of Phoenix tree leaves. As with the peak temperature, there is no appreciable difference with respect to the shape of the biomass.
4. Conclusions
An experimental study has been carried out to elucidate the thermal behaviour of coco peat briquette using thermogravimetric analysis. From the TG and DTG curves, the temperatures of degradation were identified. The effects of heating rate, density of the biomass, and shape of the biomass briquettes were also exposed. The heating rate has effect on the mass loss profile and the temperature of degradation. The decomposition is remarkably shifted to higher temperatures with the increase in the heating rate due to the sample size that hinder the heat diffusion towards inside of the sample. The density of the sample also affects the thermal decomposition. The denser sample shifts the decomposition to the higher temperatures but its effect is less pronounced to the peak temperature than that of the heating rate. The sample with greater sphericity tends to decompose at lower temperatures since it has greater contact area per unit volume. The greater contact area will facilitate the heat to diffuse towards inside the material.

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