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INVESTIGATION OF THERMAL DEGRADATION OF POULTRY PROCESSING DEWATERED SLUDGE USING THERMOGRAVIMETRIC ANALYSIS METHOD

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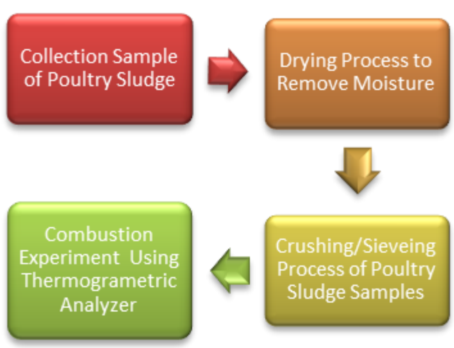
Graphical abstract



Abstract

Thermal degradation of Poultry Processing Dewatered Sludge (PPDS) was studied using thermogravimetric analysis (TGA) method. The effect of particle size on PPDS samples and operational condition such as heating rates were investigated. The non-isothermal TGA was run under a constant flow of oxygen at a rate of 30 mL/min with temperature ranging from 30°C to 800°C. Four sample particle sizes ranging between 0.425 mm to 2 mm, and heating rate between 5 K/min to 20 K/min were used in this study. The TGA results showed that particle size does not have any significant effect on the thermogravimetry (TG) curves at the initial stage, but the TG curves started to separate explicitly at the second stage. Particle size may affect the reactivity of sample and combustion performance due to the heat transfer and temperature gradient. The TG and peak of derivative thermogravimetry (DTG) curves tend to alter at high temperature when heating rate is increased most likely due to the limitation of mass transfer and the delay of degradation process.

Keywords: Heating rate, particle size, poultry sludge, TGA, thermal degradation

1.0 INTRODUCTION

PPDS is a biomass waste material from poultry processing activity at the slaughtering house which is rich in fat and protein. This solid organic waste comes from the water treatment process after going through a series of processing step such as slaughtering, bleeding, cutting and deboning. These processing steps produce substantial amount of by-product such as feathers, bone meal, blood and internal organs.

The route to convert biomass into a beneficial form of energy can be performed using the thermochemical (TCC) conversion process. Combustion is one of the way to transform biomass into a final product that can be useful for energy production. In order to transform biomass through the TCC process, a deep understanding about combustion behavior is important. The role of this study is crucial in order to predict the thermal degradation and chemical reaction that would occur during the combustion process in a real TCC facilities [1].

Thermogravimetric Analysis (TGA) is the most common and popular technique in thermal analysis studies. This method is frequently used by researchers to determine the thermal event and thermal decomposition of sample during the ramping of temperature in both combustion and pyrolysis process [2]. Moreover, TGA is a tool that gives a rapid interpretation of the fuel characteristic in terms of its pyrolysis and combustion behavior, and description of the reactivity study and parameters of the burning profiles [3].

Although the study of combustion behavior and kinetic analysis via TGA are available extensively in literatures, the investigation of important variables that affect the combustion process is very limited and usually neglected. Operating conditions such as heating rate and the physical properties of material like particle size, are the two important parameters that influence the combustion process. In order to obtain the most representative and suitable condition for thermal degradation, the parameters in the study must be taken into consideration. Thus, the aim of this work is to determine the thermal degradation and heating rate using the TGA.

2.0 METHODOLOGY

Initially, the sample used was in a sludge cake form that has a high content of moisture. Before conducting the TGA, the moisture in the sample was removed by drying in an oven at a constant temperature of 105°C until no weight loss is observed. The procedure to determine initial moisture content and time needed for the sample to dry completely is in accordance to the ASTM D1762-84 standard. Dried sample of PPDS was then manually crushed and sieved to obtain particle sizes ranging from 0.425mm, 0.6mm, 1.18mm and 2mm. The variance of particle sizes in this study is in accordance to the ASTM E2651-13 standard.

The combustion experiments were carried out using the thermogravimetiric analyzer model LabSys Evo Setaram. In order to eliminate the effect of initial mass, 10 mg of sample was set for each experiment and placed in an alumina crucible. Non-isothermal TGA was conducted with the temperature raised from 30°C to 800°C in oxygen atmosphere. The gas was purged at a constant flow rate of 30mL/min. To study the heating rate effect, the heating rate was varied from 5 K/min to 20 K/min with a 5 K/min interval.

3.0 RESULTS AND DISCUSSION

Combustion profiles in TGA provides good understanding about the reaction course of sample in oxidative atmosphere. Several stages can be clearly indicated by the observation of the TG and DTG curves. TGA combustion of PPDS can be described in three stages as reflected by the TG curves that corresponds to the DTG peaks. As shown in Figure 1(b), the three stages can be identified as evaporation of moisture (30°C-150°C), devolatilization (150°C-350°C) and char combustion (350°C-500°C) [4]. It can be seen that the first stage shows very low DTG peak. Most of the moisture content has been removed during the oven drying process. As a result, the behaviour behavior of PPDS for different particle sizes content is the incombustible component in combustion process, thus it will not be evaluated in this investigation. Second stage, or devolatilization, is a process of volatile liberation which produces char formation at the end of the reaction [5]. Devolatilisation process occur actively in the second stage compared to the final stage. This can be observed from DTG curves where the peak in the second stage is always greater than the third stage. The reason to this is due to the low carbon content left for degradation process at the third stage [6]. Depletion of fuel content caused no further reaction occurred and the TG curves are continuosly constant after 500°C.

3.1 Effect of the Particle Size

The effect of four particle sizes on thermal reactivity of sample was low during this stage. Moisture degradation were examined and the TG and DTG curves are shown in Figure 1(a) and Figure1 (b), respectively. The results indicated that there is no significant effect between particle size and thermal degradation at the initial stage (temperature lower than 200°C). The effect of particle size to the TG and DTG curves can be seen when the temperature reaches above 200°C, where the TG curve and DTG peak are explicitly separated as the particle size increases. As mentioned earlier, this temperature region is subjected to the devolatilization process. Therefore, it is apparent that sample particle size significantly influence the thermal degradation at the devolatilization stage.

Figure 1(b) shows the increasing peak height of DTG when the particle size is increased. Evidently, data of DTG peak and the corresponding temperature in Table 1 shows the relationship of particle sizes and DTG_{max} in both stages. The corresponding temperature also tends to increase withincreasing particle size. However,there were no changes of temperature for particle sizes 0.6 mm, 1.18 mm and 2 mm at the third stage. It indicated that PPDS degrades at low temperature for the finest particle size, but required higher temperature to react as the particle size increases. The findings suggest that sample reaction and combustion performance varies when particle size increases. Hence, the particle size can affect the heat transfer and temperature distribution. In order to ensure high efficiency of the combustion process, interaction between the ambient temperature and the particle's surface must be calculated precisely. Smaller particle size might reduce the temperature gradient effect and subsequently facilitate the heat transfer from the medium to the surface as well as to the inner portion of particle. An increase in particle size may lead to a temperature gradient which can result in a heat tranfer resistance [7].

3.2 Effect of the Heating Rate

To study the effect of heating rate to TGA combustion, a 0.425mm particle size was selected. Figure 2(a) and Figure 2(b) shows the TG and DTG curves of TGA combustion at four different heating rates for particle size 0.425mm. It appears that the TG and DTG curves tend to shift laterally to the right as the heating rate increases from 5 to 20 K/min at both second and third stage. This finding is in agreement with other studies [8,9]. The result indicated that there is a delay of thermal degradation when heating rate is increased due to the rapid distribution of instantaneous thermal energy in the system. The material reached the desired temperature faster than anticipated. As a result, combustion parameters such as the ignition, peak and burnout temperatures can be observed at a higher teperature [10]. Additionally, the reason of temperature shift as defined by Idris et.al. [8] was influenced by the decomposition temperature which behaves differently at different heating rate. Slower decomposition process can be detected at a higher heating rate because of the poor effectiveness of heat transfer effect. In comparison, lower heating rate is more efficient to transfer the heat as the process occurs gradually. For the lower heating rate, the DTG peaks also appear at lower temperature compared to the peaks at a higher heating rate. This indicated that the PPDS material seems to be easier to decompose at a lower heating rate than at a higher heating rate.

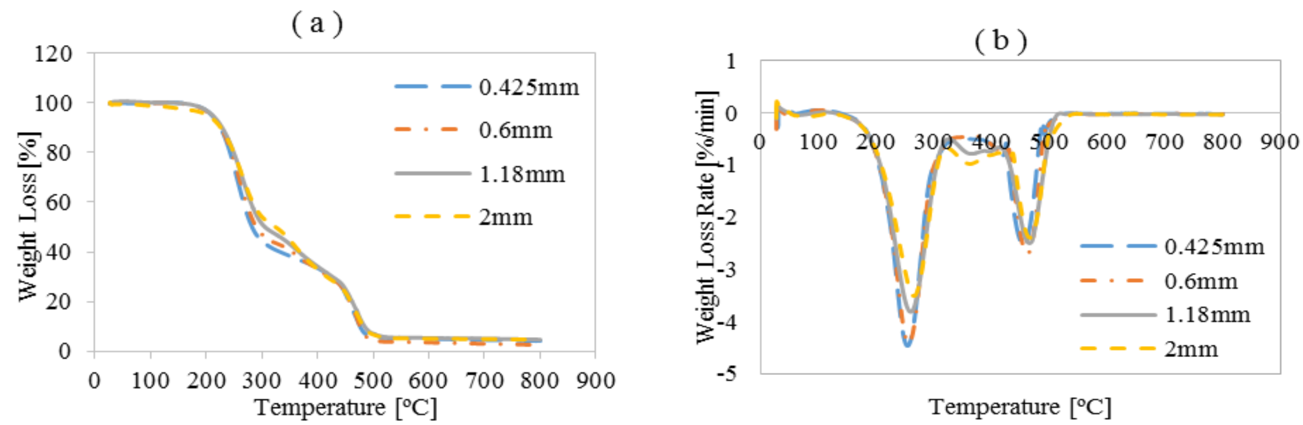


Figure 1 Combustion TGA of PPDS at 4 different particle size for heating rate of 5 K/min. (a) TG curves (b) DTG curves

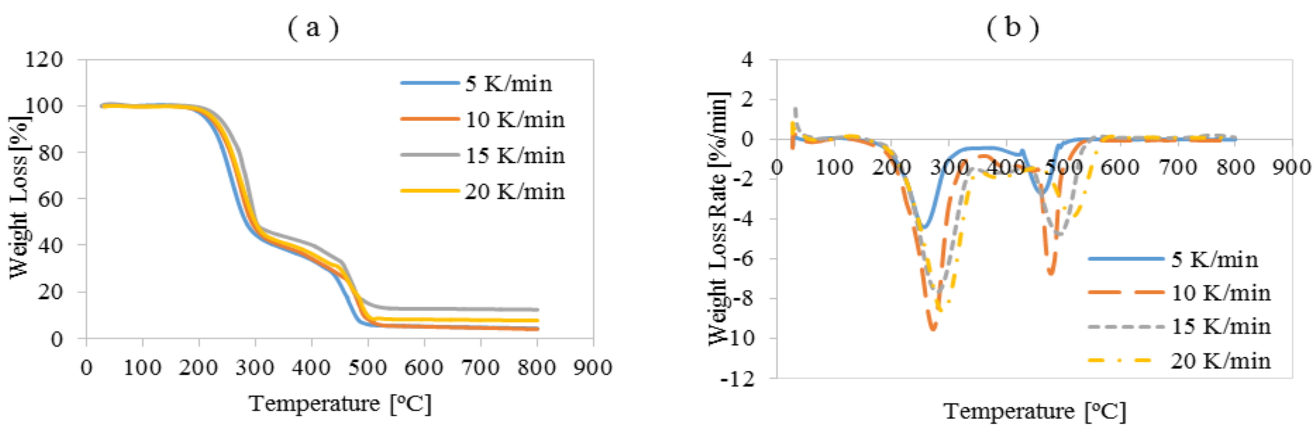


Figure 2 Combustion TGA of PPDS at 4 different heating rates for sample particle size of 0.425mm. (a) TG curves (b) DTG curve

Table 1 DTG profiles correspoding to four different particle sizes at heating rate 5 K/min

Heating Rates [K/min]	Particle Size [mm]	DTG_{max1} [%/min]	T_{max1} [ºC]	DTG_{max2} [%/min]	T_{max2} [ºC]
	0.425	-4.425	256	-2.702	463
5	0.6	-3.815	260	-2.500	466
	1.18	-3.506	266	-2.388	466
	2	-3.174	264	-2.313	466

4.0 CONCLUSION

The TGA results of PPDS to study the effect of sample particle size and heating rate during the combustion process was presented. Particle sizes and heating rates are the important parameters that can affect the combustion behavior. Two different peaks were observed in this study. The effect of the sample particle size on the thermal degradation and combustion behavior can be seen clearly at the second stage of the combustion process. TG and DTG curves tend to shift laterally to the right with respect to the heating rate increment. The outcome of this study can be a specification input for design and scaling of the reactor unit in PPDS biomass conversion in the TCC process.

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