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## Investigation of oil palm wastes' pyrolysis by thermo-gravimetric analyzer for potential biofuel production

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### Abstract

The aim of this study is to investigate the thermal degradation behaviour of oil palm trunk (OPT) and empty fruit bunch (EFB) wastes in pyrolytic environment by using thermogravimetric analyzer (TGA). The pyrolysis process was being carried out at room temperature up to 700°C in the presence of nitrogen gas flowing at the rate of 150 ml/min. The investigated parameters are particle sizes and heating rates. The particle sizes varied in the range of  $dp_1 < 0.25$  mm and  $0.25 \leq dp_2 \leq 0.30$  mm. The heating rate of 50°C/min and 80°C/min were applied to study the effect on thermal degradation during the progress of pyrolysis reaction. The decomposition of OPT shows a 'shoulder' form while EFB degrades with 2 distinctive peaks. Smaller OPT size produces 0.04-0.86% more volatile product when degraded at both heating rates. EFB on the other hand shows a 3.81-9.81% increment. Heating rates speed up the peak degradation by 1.42-1.56 mg/s at  $dp_1$  and 3.13-4.92 mg/s at  $dp_2$ . It also causes biomass to be degraded under a narrow temperature range by 21°C. This study can provide an important basis in determining suitable type of feedstock and processing parameters for bio-fuel production via advanced pyrolysis technology.

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**Keywords:** Characterization; Empty fruit bunch (EFB); Oil palm trunk (OPT); Pyrolysis; Thermogravimetric analyses (TGA); Thermal degradation

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## 1. Introduction

Malaysia is blessed with natural resources, particularly crude oil and natural gas, which are the main sources of energy. However, these are depleting energy resources and increasing demand has made it necessary for the government to embark on alternative energy sources. Rising crude oil prices have led to higher government expenditures on subsidies to keep retail fuel prices at relatively low levels. In addition, such fossil fuels emit among others, carbon dioxide (CO<sub>2</sub>), which gives rise to greenhouse effect in the atmosphere, contributing to global warming and long-term climate change. As a result, there are continuous global efforts and initiatives to protect the environment, notably commitment under the Kyoto Protocol (1997) to reduce greenhouse gas emission to an average of 5% below levels.

The European Union (EU) too has a set target to gradually increase the use of biofuel in the transport sector from 2% of the total diesel consumption in 2005 to 5.75% by 2010. Consequently, world demand for biofuel has increased. In addition, the main advantages of using this biofuel are its renewability, better quality exhaust gas emission, its biodegradability and it does not contribute to a net rise in the level of CO<sub>2</sub> in the atmosphere, and consequently to the greenhouse effect. In Malaysia, there is an abundance of biomasses such as oil palm waste, rice husk and wood saw dust. While much research efforts have been carried out to utilize them for production of value-added products, the commercial aspect is still not fully implemented, some are returned to the field as fertilizers. Malaysia can be one of the leading countries in the development of renewable energy if the exploitation of biomass is actively studied. Besides, the implementation of biofuel program in Malaysia is in line with the government policy of ensuring sustainable development of the energy sector as well as promoting a cleaner environment.

Pyrolysis is one of the most promising thermal conversion processes to transform biomass into a more convenience biofuel sources. During the process, biomass is thermally decomposed without an oxidizing agent to produce liquid oil, solid charcoal, and gases. The process converts biomass into liquid fuel with a high volumetric energy density. The char contain most of the inorganic components and it can be used as an energy carrier or as a soil fertilizer. The pyrolysis gas can be used to generate electricity or to provide heat for the pyrolysis process. This gas consists mainly of carbon monoxide, carbon dioxide and light hydrocarbons. The liquid oil can be directly used without any upgrading as a fuel oil in many combustion applications such as boilers. Upgrading is probably needed if the bio-oil is to be applied to smaller engines. The liquid oil is composed of a large variety of higher molecular weight species, organic acids, aldehydes, alcohols, phenols and other oxygenates. This oil is also known as a pyrolysis liquid, bio-oil or tar and has a lower heating value of 15-20 MJ/kg, about half that of conventional fuel oil. The pyrolysis oil can undergo secondary reactions to be further broken down into gas, refractory tar and water.

Many researchers studied thermal decomposition of biomass by thermogravimetric analysis (TGA) to gain better understanding of pyrolysis process in a well-controlled environment. Thermogravimetric analysis (TGA) is the most common technique and is widely used for kinetic analysis of devolatilization process. Numerous works has described TGA analysis and behaviour of various types of biomass during thermal degradation. Biomass consists of three major components which are cellulose, hemicellulose and lignin. The thermal degradation of each component occurs at different temperature by different pathways. The objective of this study is to investigate the pyrolysis of Malaysia's oil palm wastes such as oil palm trunk (OPT) and empty fruit bunch (EFB) by thermogravimetric analyzer (TGA) at different heating rates and biomass particle sizes. In addition, the thermal degradation of these biomasses also is studied.

## 2.0 Materials and experimental procedures

### 2.1 Materials preparation and characterization

An oil palm trunk (OPT) and empty fruit bunch (EFB) used in this experiment was supplied by Malaysian Palm Oil Board (MPOB). The feed stocks were first milled and sieved into smaller particle

size of <0.30 mm. The characterizations of both OPT and EFB samples were performed in order to obtain its ultimate, proximate and high heating value (HHV). The ultimate analysis was carried out using elemental analyzer which determines the content of C, H, N and S in the feedstock. The proximate analysis was conducted using thermogravimetric analyzer (TGA) to analyze volatile matter (VM), fixed carbon (FC), moisture content and ash content in both investigated biomass samples. The higher heating value of OPT and EFB was determined using bomb calorimeter.

## 2.2 Experimental procedures

TGA was carried out in the presence of nitrogen (N<sub>2</sub>) at the flowing rate of 150 ml/min. EFB and OPT samples between 0.5 and 1.0 g was pyrolyzed to a maximum temperature of 700°C. The sample was first heated to 110°C and kept at that temperature for 30 minutes to remove any moisture. After that, the samples were individually heated at heating rates of 50°C/min and 80°C/min until 700°C.

## 3.0 Results and discussion

### 3.1 Properties and composition of feedstock

Table 1 shows the properties and characteristic of OPT and EFB samples. As can be seen, there are major differences between these feed stocks, particularly the volatile matter and fixed carbon contents. An OPT has a higher amount of volatile matter and a lower fixed carbon content as compared to the EFB sample. Higher value of ash content in OPT also affects the heating value. The ultimate analysis listed in Table 1 shows significant variation in carbon and oxygen content whereas there are slight variations in hydrogen, nitrogen and sulphur content in EFB and OPT.

Table 1. Properties of OPT and EFB

Analysis	OPT	EFB	
Proximate analysis (db wt %)	Moisture content	2.1	2.3
	Ash content	4.3	3.1
	Volatile matter	76.7	73.2
	Fixed Carbon	16.9	21.4
	High heating value (HHV) (MJ/Kg)	17.2	18.5
Ultimate analysis (db wt %)	Carbon (C)	41.6	45.4
	Hydrogen(H)	6.8	6.4
	Nitrogen (N)	0.4	0.3
	Sulphur (S)	0.9	0.4
	Oxygen (by difference)	50.4	47.5

3.2 Experimental results

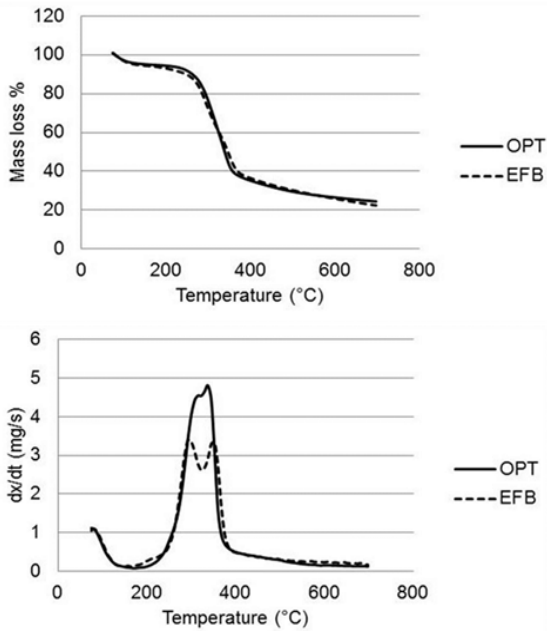


Fig. 1. A TGA-DTG plot of OPT and EFB at heating rate of 50 °C/min for  $dp_1$ .

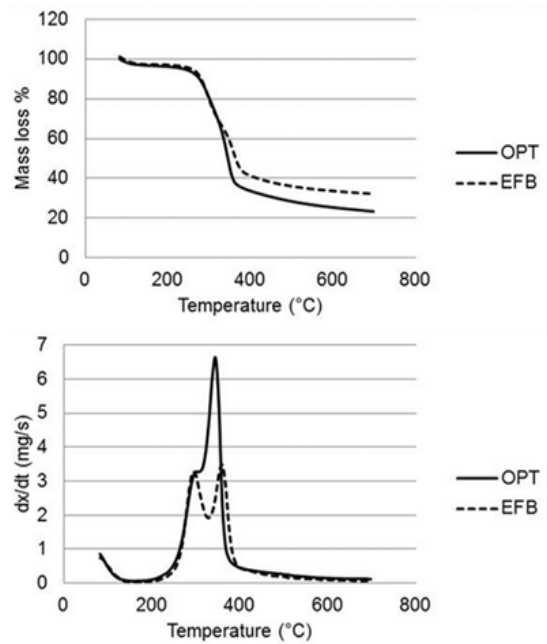


Fig. 3. A TGA-DTG plot of OPT and EFB at heating rate of 50 °C/min for  $dp_2$ .

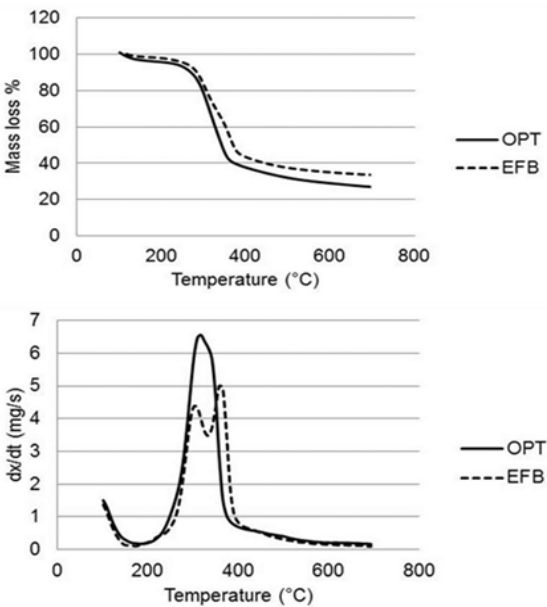


Fig. 2. A TGA-DTG plot of OPT and EFB at heating rate of 80 °C/min for  $dp_1$ .

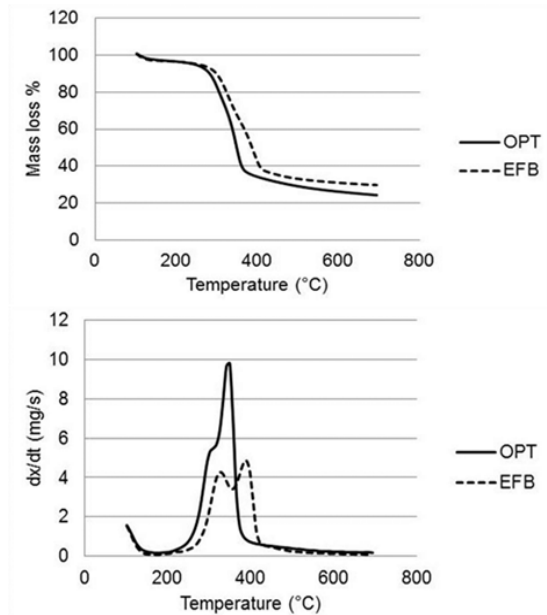


Fig. 4. A TGA-DTG plot of OPT and EFB at heating rate of 80 °C/min for  $dp_2$ .

Fig. 1 to Fig. 4 show the TGA and DTG curves for both EFB and OPT, pyrolyzed at heating rate of 50°C/min and 80°C/min. TGA curve displays weight loss as a function of temperature in a controlled atmosphere, whereby DTG curve emphasizes the zone of reaction where various reaction steps are taking place over the entire temperature range. The weight loss started at 150-500°C and terminated around 650°C at all operating conditions for both OPT and EFB samples. Fig. 1 shows a TGA-DTG curves of OPT and EFB at a heating rate of 50 °C/min for particle size of < 0.25 mm ( $dp_1$ ). In general, the pyrolysis of any biomass can be divided into three phases which are drying and evaporation of light components (phase I), devolatilization of hemicellulose and cellulose (phase II) and decomposition of lignin (phase III). Phase I occurs at temperature below 150°C, phase II starts from 150°C to 450°C and finally phase III is attained at temperature above 450°C.

Fig. 1 shows that for particle size  $dp_1$  heated at 50°C/min, the amount of char left at the end of pyrolysis process is 22.47% for EFB and 24.49% for OPT. Larger particle size decreases the amount of biomass conversion whereby the final residue is 32.28 % and 25.35% for EFB and OPT respectively as shown in Fig. 3. It is well agreed in the literature that larger particle sizes yields more residue because of poor heat transfer to the inner biomass surfaces which leads to low average particles temperature [1,2]. Previous study conducted by Sukiran et al. [3] shows that optimum bio-oil yield was obtained for particle size of 0.091-0.106 mm, and Ruengvilairat et al. [4] concluded that optimum EFB particle size is > 1.180 mm. Larger particle size is favourable for char and gas production.

Higher heating rate is expected to increase the amount of volatiles in pyrolysis process. In this study however, the effect is adverse. At heating rate of 50°C and particle size of  $dp_1$ , the volatiles yield for OPT is 73.41%, while at 80°C/min the amount of volatiles was reduced by 2.57%. Same result is reported for EFB which recorded 11.20% decrement. At  $dp_2$  the results is not significant for OPT but EFB recorded a 2.42% increment when pyrolyzed at higher heating rate. While the effect of heating rate towards volatile content production is inconsistent, it does increases the peak degradation rate for each tested samples. For  $dp_1$ , the degradation rate increases by 1.42 mg/s at heating rate 50°C/min, while at heating rate 80°C/min, the increment is 1.56 mg/s. Larger particle size ( $dp_2$ ) shows greater changes with 3.13 mg/s and 4.93 mg/s respectively. It can be concluded that higher heating rate helps in degradation speed but insignificantly affects the amount of volatiles produces.

A study has shown that biomass with more cellulose and hemicellulose contents (or holocellulose content) will produces more volatiles compared to woody biomasses [5]. OPT and EFB constitutes of 76.30% and 65.5% of holecellulose accordingly [6]. Under different tested parameters, OPT produces 5.46-8.93% more volatiles, except during  $dp_1$  and heating rate=50°C/min where EFB yields 2.02% more volatiles. DTG graphs for EFB display two distinctive peaks, in which the first peak is 0.22-0.62 mg/s lower than the next. The first peak corresponds to the degradation of lower molecular weights components (hemicellulose) from 180°C to 310°C and second peaks indicates cellulose degradation which occurs between 320°C and 410°C. OPT on the other hand show a 'shoulder' pattern, which is caused by the amount of cellulose and hemicellulose in each type of biomass. It is noted that when the temperature reaches 650°C, the degradation rates are no longer significant as most volatiles had already been pyrolysed.

#### 4.0 Conclusion

There are many factors influencing a pyrolysis process. The main factors discussed in this paper are the effect of particle size, heating rate and the properties of biomass itself. Smaller OPT size produces 0.04-0.86% more volatile product when pyrolyzed at both heating rates. EFB on the other hand shows 3.81-9.81% increment. Heating rates speed up the peak degradation by 1.42-1.56 mg/s at  $dp_1$  and 3.13-4.92 mg/s at  $dp_2$ . It also causes biomass to be degraded under a narrow temperature range by 21 °C. High lignin content in EFB lowers the amount of volatiles produces which is in accordance to literature findings. The peak degradation rate of OPT is also much higher than OPT which is 9.79 mg/s compared to 4.86 mg/s (at

dp<sub>2</sub> and heating rate 80°C/min). It can be concluded that OPT is more suitable to be used as fast pyrolysis feedstock because it degrades faster and produces more volatiles.

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