



# Evaluation of Oil Palm Biomass Potential for Bio-oil Production via Pyrolysis Processes

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**Abstract:** The yield and quality of bio-oil obtained from pyrolysis processes depends on many factors, including the pyrolysis types, reactor types, operating conditions and biomass property. The objective of this study was therefore to evaluate the potentiality of oil palm biomass, including oil palm trunk (OPT), oil palm fronds (OPF), oil palm decanter (DC), and oil palm root (OPR) for producing bio-oil via pyrolysis processes. The potentiality of oil palm biomass was considered in terms of proximate analysis, ultimate analysis, higher heating value, potential use as energy equivalent to fossil fuels, thermogravimetric analysis (TGA) and lignocellulose content. The results showed that the moisture content of dried samples was in the range of 7.5-10.7% (w.b), which was relatively low and appropriate for pyrolysis processes. The volatile content of OPT and OPF was higher than 72% (wt.). The carbon, oxygen and hydrogen content of oil palm biomass samples were in the range of 41.5-45.6, 30.7-40.2 and 5.7-5.9% (wt.), respectively. The higher heating value (HHV) and potential use as energy of the samples was relatively low compared to the HHV of fossil fuels. The OPT and OPF had high cellulose and hemicellulose content, while also providing low lignin content compared to the lignin content of DC and OPR. The TGA results showed that the thermal decomposition of the samples took place within the range of 200–450°C, with the lignin content strongly affecting the thermal decomposition trend. These results revealed that the selected oil palm biomass exhibited potentiality for producing bio-oil via pyrolysis processes, particularly the OPT and OPF.

**Keywords:** Alternative energy, biomass, bio-oil, bioenergy, oil palm biomass, property of biomass, pyrolysis

## 1. Introduction

In the current world, fossil fuels are used extensively to meet modern society's ever-increasing demands, especially for electricity generation, transportation and industrial purposes. The higher demand for fossil energy leads to the depletion of fossil fuels while also creating severe environmental impacts through global warming and climate change [1]. In light of this unsustainable situation, many countries across the globe are making efforts to overcome these issues by searching for and innovating new sources of energy. Utilizing renewable energy (RE) and alternative energy (AE)

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resources, including wind, hydro, solar, geothermal, wave and biomass, remains a major challenge in many countries. The potentiality of RE and AE in each country or region is dependent on multiple factors such as location, weather, plantation, agricultural activity and industrial processing. In contrast with the previously mentioned statistics, RE and AE, especially biofuels are among the fastest growing sources of energy resources. In 2017, British Petroleum (BP) reported that biofuels contributed around 4% of the overall increase from the previous year's production [1]. This is because biofuels represent the best replacement for fossil fuels. The use of biofuels is most commonly adopted by the countries in which agriculture and the agro-industry are major contributors to the national economy. Most of the Asian countries are largely dependent on the agriculture sector and this includes Thailand.

Thailand has a tropical climate i.e. exhibiting hot and humid conditions throughout the year. With its climatic condition, Thailand is an appropriate location for growing a number of crops with high potential for the biomass and biofuels, including rice, cassava, corn, rubber trees and oil palm trees [2]. The plantation, harvesting and processing of these agricultural products provides many biomasses such as rice straw, rice husks, cassava stalks, cassava roots, corn stalks and leaves, rubberwood and oil palm biomass. In 2017, the plantation area devoted to oil palm trees in Thailand was 710,000 hectares which was 5.6% more than in 2016 [3]. The harvesting and processing of oil palm fresh fruit bunches provide many biomasses, including oil palm fronds, empty fruit bunches, oil palm kernel shells, oil palm fiber, oil palm decanter and sewage sludge. The replantation of oil palm tree also provides the big source of oil palm biomasses, including oil palm trunks, oil palm fronds and oil palm roots. The Department of Alternative Energy Development and Efficiency (DEDE) [4], Ministry of Energy of Thailand, reported that some of oil palm biomass materials have already been used as biofuels to generate heat and power in the oil palm factories. However, there are some oil palm biomass materials, including empty fruit bunches (EFB), oil palm trunks (OPT), oil palm fronds (OPF), oil palm roots (OPR), oil palm decanter (DC), and sewage sludge (SW), that still have high potential but as yet unexploited potentiality for using as biofuels or bioenergy. The potentiality of EFB, OPT and OPF is remaining of 379.51, 350.38 and 683.51 ktoe, respectively [4].

#### Nomenclatures

ADF	Acid detergent fiber
ADL	Acid detergent lignin
AE	Alternative energy
BP	British Petroleum
C	Carbon
DC	Oil palm decanter
DEDE	Department of Alternative Energy Development and Efficiency
DTA	Differential thermal analysis
EFB	Empty fruit bunches
H	Hydrogen
HHV	Higher heating value
LPG	Liquefied petroleum gas
N	Nitrogen
NG	Natural gas
NDF	Neutral detergent fiber
O	Oxygen
OPF	Oil palm fronds
OPR	Oil palm roots
OPT	Oil palm trunks
RE	Renewable energy
S	Sulphur
SW	Sewage sludge
TGA	Thermogravimetric analysis

The conversion of biomass into biofuels or bioenergy can be performed through several processes, including mechanical conversion processes (size reduction by chopping, pelletization and briquetting), thermochemical conversion processes (combustion, gasification, pyrolysis and torrefaction), biochemical conversion processes (fermentation and anaerobic digestion), as well as combined processes such as the pelletization of torrefied biomass [5-10]. The criteria for choosing a biomass conversion process depend on many factors such as the type of biomass (solid, liquid or mixed sample), biomass property, desired energy product and utilization, cost, storage and transportation. This is due to the fact that the conversion of biomass through these processes provides different types and forms of biofuel and bioenergy. For example, chopping rubberwood to produce wood chips provides a solid biofuel which has high energy density compared to raw rubberwood. The wood chips are also easy to store, handle and transport. Combustion is the conventional biomass conversion process that is widely used worldwide because it is a simple process. The energy product obtained from combustion is in the form of heat which can be used for many purposes such as steam and power generation. The main



disadvantages of heat are that it is not suitable for storage and transportation. The pyrolysis process is one of thermochemical conversion processes that can be used for converting biomass to bio-oil which is in the form of liquid biofuels. The main advantages of bio-oil are that it has high energy density compared to raw biomass and bio-oil is also easy to store, handle and transport [11-14]. Bio-oil can be used for many purposes, including directly as fuel in boilers, after upgrading as fuel in engines, or turned into a high-value product for food and chemical processes [15-16].

Pyrolysis is the thermal decomposition of macromolecular materials (municipal solid wastes, plastic wastes, waste lubricant oil and biomass) in the absence of oxygen conditions. The product obtained from the pyrolysis of biomass is pyrolysis oil which is normally called "bio-oil" [17-19]. The yield and quality of bio-oil depend on many factors such as the pyrolysis types, reactor types, operating conditions and biomass types and property [10,15,20]. Most types of biomass, both woody and non-woody, are lignocellulosic materials. The property of lignocellulosic biomass strongly influences the bio-oil yield and quality [21-23]. The physical and chemical properties, such as size, moisture content, volatile content, elemental component, heating value and lignocellulose content are example properties that affect the bio-oil yield and quality [15,17,20,22].

As already mentioned, this study aimed to evaluate the potentiality of selected oil palm biomass in Thailand for producing bio-oil via pyrolysis processes. The selected oil palm biomass used in this study included oil palm trunk (OPT), oil palm fronds (OPF), oil palm decanter (DC) and oil palm roots (OPR). The potentiality of the oil palm biomass samples was considered by proximate analysis, ultimate analysis, higher heating value, thermogravimetric analysis (TGA) and lignocellulose content.

## 2. Materials and Methods

### 2.1 Oil Palm Biomass Preparation

The oil palm biomass used in this study included oil palm trunk (OPT) without bark, oil palm fronds (OPF) without leave, oil palm decanter (DC), and oil palm roots (OPR). The OPT, OPF and OPR were obtained from oil palm trees grown in Klong Thom District, Krabi Province, Thailand. The age of the oil palm trees was 25 years. The DC was obtained from the Thaindo Palm Oil Factory, in Lam Thap District, Krabi Province, Thailand. For the OPT, it was reduced in size to approximately 0.05 m × 0.05 m × 1.5 m by sawing before chopping. The fresh OPT, OPF and OPR were chopped to reduce the size before drying in a solar greenhouse. The chopped samples were dried until they had a moisture content of lower than 10% (w.b.). Then the dried samples were ground by a grinding machine which was equipped with a 2 mm sized sieve.

### 2.2 Proximate Analysis

The determination of moisture content, fixed carbon content, ash content and volatile matter was performed by proximate analysis. These compositions were determined by the thermogravimetric analyzer (TGA) technique using Macro TGA (LECO, UK), according to the ASTM D7582 procedure. The results were reported as percentages by weight (% wt.)

### 2.3 Ultimate Analysis

The elemental composition of the oil palm biomass samples, including Carbon (C), Nitrogen (N), Hydrogen (H), Oxygen (O) and Sulphur (S) content, was determined by a Thermo Scientific FLASH 2000 Organic Elemental Analyzer (Thermo Scientific, Italy). The results were reported as percentages by weight (% wt.)

### 2.4 Determination of Higher Heating Value

The higher heating value (HHV) of the oil palm biomass samples was determined by bomb calorimeter (IKA C5000, Germany). The values obtained from the bomb calorimeter were then compared to the HHV, which was calculated by the correlation of Buckley et al [24] as shown below:

$$\text{HHV} = 0.336 \text{ C} + 1.418 \text{ H} - (0.153 - 0.00072 \text{ O})\text{O} + 0.0941 \text{ S} \quad (\text{MJ/kg}) \quad (1)$$

Where the C, H, O and S are the elemental composition (% wt.) obtained from ultimate analysis.

### 2.5 Estimation of Potential Use as Energy Equivalent to Fossil Fuels

The HHV of the oil palm biomass samples was compared to the HHV of fossil fuels, including coal (Bituminous), crude oil, natural gas (NG) and liquefied petroleum gas (LPG). The results were reported in terms of potential use as energy equivalent to fossil fuels. The reference HHV of coal, crude oil, NG and LPG is 28.87 MJ/kg, 38.78 MJ/L, 38.95 MJ/m<sup>3</sup> and 50.08 MJ/kg, respectively.

## 2.6 Thermogravimetric Analysis (TGA)

A technique of thermal analysis in which chemical and physical properties of materials are stated as a function of temperature with respect to a constant rate of heating is known as thermogravimetric analysis (TGA). The samples are subjected to a program which is calibrated with temperature to study the changes in the mass due to various thermal activities like absorption, oxidation, reduction and decomposition. Hence, it is used to determine how much gaseous matter is decomposed during the reactions in biomass and some other volatile products. Thermogravimetric analyzers (Perkin Elmer, USA) are used to determine the properties in this study.

## 2.7 Determination of Lignocellulose Content

The lignocellulose contents of the oil palm biomass samples were evaluated by using a method developed by Goering and Van Soest [25] and Soest et al. [26]. According to this method, three different procedures were performed to calculate the lignocellulosic contents. The percentage of cellulose, hemicellulose and lignin were determined in terms of acid detergent fiber (ADF), neutral detergent fiber (NDF), and acid detergent lignin (ADL). Then, the percentage of cellulose, hemicellulose and lignin was calculated.

## 3. Results and Discussion

### 3.1 Proximate Analysis Results

Fig. 1 shows the proximate analysis results of the oil palm biomass samples. The results revealed that the oil palm biomass samples had moisture content, volatile matter, fixed carbon content and ash content in the ranges of 7.60-10.73%, 61.55-74.06%, 11.81-20.07% and 2.89-13.70%, respectively. The moisture content of the oil palm biomass samples after drying in a solar greenhouse was relatively low, implying that the biomass samples are appropriate for producing bio-oil via the pyrolysis process. This is because the initial moisture content of the biomass strongly influences the water content in the bio-oil. Aside from the initial moisture content of the biomass, the water content of the bio-oil also depends on the reaction water [27-29]. Normally, the content of reaction water is lower than the water content in the initial moisture content of the biomass. The presence of water in bio-oil affects its quality. Bio-oil that contains water has both advantages and disadvantages. The advantage of water in bio-oil is that it helps to improve the flow characteristics by reducing the viscosity. Water in bio-oil also leads to a more uniform temperature profile in the combustion cylinder of a diesel engine as well as to lower NO<sub>x</sub> emissions. On the other hand, the presence of water in bio-oil leads to a low heating value and flame temperature [30]. For these reasons, many works related to pyrolysis processes have suggested that the initial moisture of biomass before pyrolysis should be lower than 10% (w.b.) [27-29]. However, a reduction of the moisture content of fresh biomass requires the dryers such as rotating drum and fluidized bed dryers. These dryers consume energy and take time, thereby affecting the production cost of the bio-oil. Thus, drying fresh biomass with solar energy or waste heat (flue gas and steam) may be an alternative solution that helps to reduce energy costs.



Fig. 1 - Proximate analysis results

Many works have studied the effects of the volatile matter, fixed carbon and ash content in biomass on bio-oil yield and quality. They have shown that in the biomasses with high volatile matter, a high volume of bio-oil yield is obtained from pyrolysis processes. The volatile matter of biomass is the part that can be decomposed by heat and turned into vapor that can then be condensed as bio-oil [27-29,31]. The quantity of the bio-oil obtained depends on the amount of condensable vapor. The fixed carbon and ash content are the solid parts that remain after heating under specific conditions. The biomass with high fixed carbon content is appropriate for producing bio-char which is not suitable for bio-oil production because it will lead to low bio-oil yield. The ash content is determined by the combustion of the volatile

and fixed-carbon compositions. The biomass with high ash content will produce a lower bio-oil yield [29,31]. The results from this study show that the OPT and OPF seem to be appropriate for bio-oil production via pyrolysis processes. This is due to the fact that they had high volatile matter, low fixed carbon, and low ash content.

### 3.2 Ultimate Analysis Result

Fig. 2 presents the ultimate analysis results, including the carbon, nitrogen, hydrogen, sulphur and oxygen content of the oil palm biomass samples. The results showed that the organic elemental contents, including carbon (C), hydrogen (H), nitrogen (N), oxygen (O) and sulphur, of the oil palm biomass samples were in the ranges of 41.45-45.57, 5.66-5.92, 0.18-2.16, 30.74-40.18 and <0.01-0.02 % (wt.), respectively. These results indicated that the oil palm biomass samples used in this study contained high proportions of carbon and oxygen. For the hydrogen content, it can be seen that this was relatively low in the oil palm biomass samples. A higher oxygen content in biomass leads to a reduction in the heating value. Also, the bonds between carbon-oxygen and carbon-hydrogen have energy levels lower than the bonds between carbon-carbon. The biomass which has high carbon, high hydrogen and low oxygen levels is suitable for thermochemical conversion processes. Several studies have found that biomass materials with low mineral and nitrogen contents are suitable for bio-oil and syngas production. In contrast with these results, the lower contents of nitrogen and sulphur will contribute to lower levels of sulphur oxides, while some sulphur remains as ash in the furnace [27,31-32].

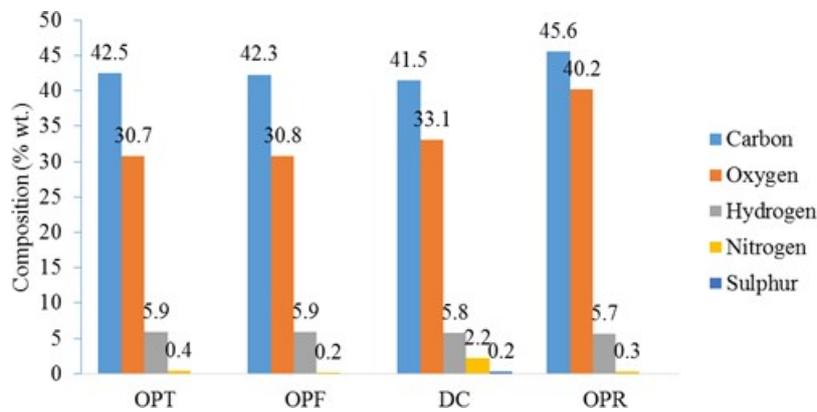


Fig. 2 - Ultimate analysis results

### 3.3 Higher Heating Value and Potential Use as Energy Equivalent to Fossil Fuels

Table 1 shows the higher heating value (HHV) and potential use as energy equivalent to fossil fuels of the oil palm biomass samples. It reveals that the HHV of the samples was in the range of 15.81-17.00 MJ/kg. These HHVs were calculated against equivalent quantities of fossil fuels, including crude oil, coal, LPG and NG. The potential use of the oil palm biomass samples as energy equivalent to crude oil, coal, LPG and NG was 0.41-0.52 L, 0.55-0.70 kg, 0.32-0.40 kg and 0.41-0.52 m<sup>3</sup>, respectively. The results show that among all of the analyzed samples, DC has the highest heating value, followed by OPR, OPT, and OPF.

Table 1 - Higher heating value and potential use as energy equivalent to fossil fuels

Biomass	HHV (MJ/kg)	Potential use as energy equivalent with fossil fuels			
		Crude oil	Coal	LPG	NG
		(L)	(kg)	(kg)	(m <sup>3</sup> )
OPT	16.11	0.42	0.56	0.32	0.41
OPF	15.81	0.41	0.55	0.32	0.41
DC	17.00	0.52	0.70	0.40	0.52
OPR	16.30	0.47	0.63	0.36	0.48

### 3.4 Lignocellulose Content

Table 2 shows the lignocellulose content of the oil palm biomass samples. It is well known that the main components of lignocellulosic biomass are cellulose, hemicellulose and lignin. Beside these three main components, the

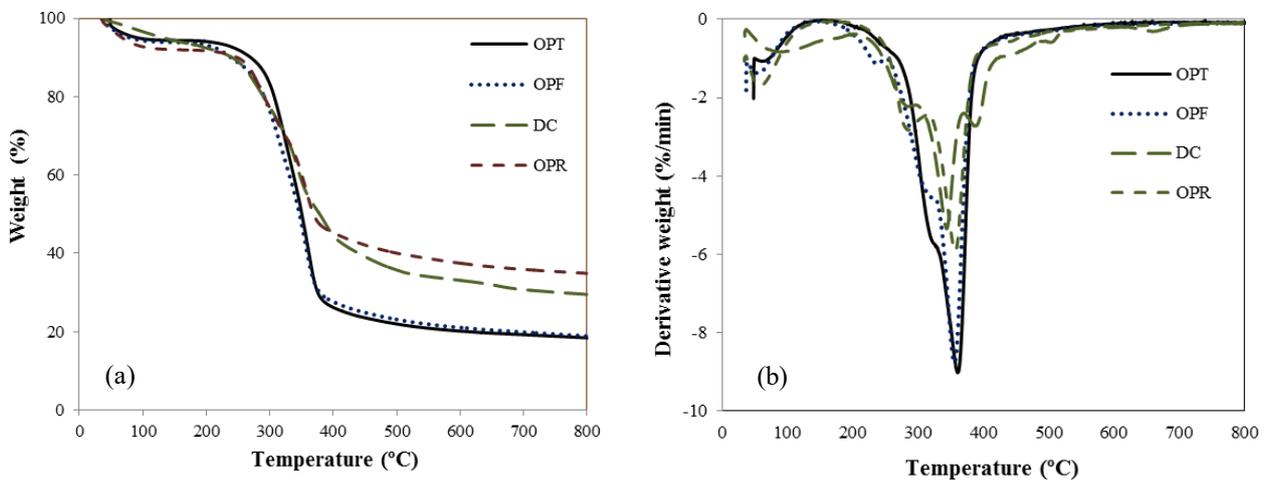
lignocellulosic biomass also comprises a small amount of extractives and ash [31-33]. The results from this study reveal that the oil palm biomass samples had cellulose, hemicellulose and lignin levels ranging from 21.85-54.35, 13.51-25.97 and 6.64-29.26 (% wt.), respectively. It can be seen that the OPT and OPF had relatively high levels of cellulose and hemicellulose, but they provided low levels of lignin. The lignin content of the OPR and DC was higher than the lignin content in the OPT and OPF. Recent research has found that cellulose and hemicelluloses contribute to the bio-oil production yield, while lignin yields provide larger proportions of solid char. Moreover, recent studies have also reported that higher lignin content in biomass may increase the average molecular weight and viscosity but decrease the water concentration of the bio-oil [31-33].

**Table 2 - Lignocellulose content of oil palm biomass samples**

Biomass	Chemical composition (% wt.)			
	Cellulose	Hemicellulose	Lignin	Other
OPT	39.40 ± 0.77	25.97 ± 1.17	6.64 ± 0.31	27.99 ± 0.41
OPF	54.35 ± 0.29	20.72 ± 0.12	8.96 ± 0.26	15.96 ± 0.53
DC	21.85 ± 0.41	13.51 ± 0.93	20.91 ± 0.32	28.17 ± 0.49
OPR	49.00 ± 2.55	19.19 ± 0.06	29.26 ± 0.07	2.55 ± 0.36

### 3.5 Thermogravimetric Analysis

Fig. 3 (a) and (b) show the thermal decomposition of the oil palm biomass samples at different temperatures. It can be seen that the decomposition of the samples due to heat had three states. The first state was at 50-200°C, during which the weight of the samples decreased in a steep manner. This is due to the weight decreasing from the evaporation of the moisture content and the light volatile matter. After the evaporation of the moisture and light volatile matter, and as the temperature of the sample also increased, the thermogravimetric analysis (TGA) and differential thermal analysis (DTA) curves showed that the thermal decomposition of the oil palm biomass samples took place within the range of 200–450°C and then the thermal degradation of the samples was very slow, decreasing in the final state.



**Fig. 3 - TGA (a) and DTA; (b) of oil palm biomass samples**

The weight of the samples decreased in second state due to the decomposition of lignocellulose content and its transformation into vapor. There are three principal classes of thermally degradable biopolymers in a lignocellulosic biomass, namely cellulose, hemicelluloses and lignin. The degradation path ways of these components have been investigated separately. The researchers found that the decomposition of hemicellulose, generally represented by xylan, mainly takes place within the temperature range of 250-350°C, followed by cellulose decomposition, which primarily occurs in the temperature range of 325-400°C with levoglucosan as the main pyrolysis product. Recent investigations have reported that lignin was the most stable component, decomposing in the higher temperature range of 300–900°C [28,31-36]. Fig. 3 also shows that the OPT and OPF had the same trend of thermal decomposition, but that trend was

different from the thermal decomposition of DC and OPR. This is due to the fact that the DC and OPR had a higher lignin content than the OPT and OPF.

#### 4. Summary

This study evaluated the potentiality of oil palm biomass, including oil palm trunk (OPT), oil palm fronds (OPF), oil palm decanter (DC) and oil palm root (OPR), for producing bio-oil via pyrolysis processes. The potential use of the selected oil palm biomass samples was considered in terms of proximate analysis, ultimate analysis, heating value, potential use as energy equivalent to fossil fuels, thermogravimetric analysis (TGA) and lignocellulose content. The results showed that the moisture content of the dried samples was in the range of 7.5-10.7% (w.b), which was relatively low and appropriate for pyrolysis processes. The volatile matter of the OPT and OPF was higher than 72% (wt.). The DC and OPR had high ash content. The carbon, oxygen and hydrogen content of the oil palm samples were in the range of 41.5-45.6, 30.7-40.2 and 5.7-5.9% (wt.), respectively. The higher heating value (HHV) of the samples was in the range of 15.81-17 MJ/kg, which was relatively low compared to the HHV of fossil fuels. The cellulose, hemicellulose and lignin of the samples were 21.85-54.35, 13.51-25.97 and 6.64-29.26% (wt.), respectively. The OPT and OPF had high cellulose and hemicellulose content, while provided low lignin content compared to DC and OPR. The TGA results showed that the thermal decomposition of the samples took place within the range of 200–450°C, with the lignin content affecting the thermal decomposition trend. These results revealed that the selected oil palm biomass samples had the potentiality for producing bio-oil via pyrolysis processes, particularly the OPT and OPF.

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