

**OIL PALM AND COCONUT FRONDS PYROLYSIS IN A FIXED BED REACTOR****\*Vivian Chinenye Akunne, Dr. Alfred Ochonogor and Prof. Paul Ejikeme**

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**Abstract**

A fixed bed reactor was used to pyrolyze oil palm frond (OPF) and coconut frond (CF). In this work, the effects of pyrolysis temperature and time were investigated. The products obtained from pyrolysis were liquid, char and gas. The ultimate, proximate analysis and thermogravimetric analysis (TGA) were performed to evaluate the chemical and thermal properties of the biomass fronds. The physiochemical analysis, ultimate analysis and chemical components using FTIR and GC-MS found in bio-oil were identified. The result shows that the optimum yield of bio-oil in OPF is 75mins and 600°C while for CF, it was 75mins and 800°C. The bio-oil's chemical composition corresponds to a mixture of several aromatic and oxygenated molecules, such as aldehydes, phenols, ketones, and carboxylic acids.

**Keywords:** Pyrolysis, Bio-oil, Biomass, Oil palm frond, Coconut frond.

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**INTRODUCTION**

For many years, the world has relied on fossil fuels to meet its energy demands, but these sources are not renewable. The production of renewable energy sources from the sun, wind, hydropower, and biomass-based biofuels has begun in several countries (Chopra *et al.*, 2024). Although biomass-based renewable energy is better than fossil fuels, and its viability depends on factors like feed availability, climate, and production costs. Biomass, such as the fronds of coconuts and oil palms, is usually produced as waste by the process of cutting and replanting plants. Nigeria, Malaysia, and Indonesia are rich in oil palm fronds. Due to ideal tropical climate conditions needed for its growth, oil palm is a highly significant crop in Nigeria and is mainly grown in the southern parts of the nation (Suwajittanont *et al.*, 2022) with over 3.5 million hectares of land dedicated to oil palm plantations, Nigeria ranks as the fourth-largest producer of palm oil worldwide (Okafor *et al.*, 2022). Prior to Indonesia becoming the world's leading producer in 2007, Malaysia held a 51% global share of the oil palm market in 1995 (Listiningrum *et al.*, 2022). Another energy source is coconut fronds, which are abundant in Nigeria and India (CBBR, 2010). The coconut tree (*Cocos nucifera*) is grown more in India at Kerala part with an area of 10.20 hectares and produces 5911 million nuts (Peter, 2009). Biomass is converted into fuel by biochemical and thermochemical routes. The biochemical process occurs in anaerobic fermentation or digestion with bacteria (Bridgwater, 2012). While thermochemical reactions occur in thermal environments and result in the production of solid, liquid, and gaseous products. Using pyrolysis, gasification, liquefaction, and combustion, this process can be repeated (Cardoso *et al.*, 2016). Pyrolysis is the most widely used of these methods. According to (Wang *et al.*, 2023), pyrolysis involves the thermal breakdown of materials which contains little or no oxygen. Based on the conditions, pyrolysis converts biomass into char, gases, and bio-oil. The pyrolysis gas made is a potential source of hydrogen due to its significant content in the gas (Abbas-Abadi *et al.*, 2014).

This characteristic can have a substantial influence on the environment, with about 95% of H<sub>2</sub> which comes from fossil fuels. The share of this product in the energy market is increasing due to the growing demand for zero fuel emissions while biochar and pyrolysis oil can be used as energy raw materials or as base substance to produce various chemicals (Ouari *et al.*, 2017). Increasing the number and quality of the intended items is made possible through optimization, which reduces the cost of production of the various parameters that affect production during conversion of biomass to biofuel (Alias *et al.*, 2014). According to (Cai *et al.*, 2021), the important component of the pyrolysis process is the reactor and the efficiency with which organic matter is converted into energy (gas, liquid, or solid fuels) during pyrolysis depends on the type of reactor that is used. In this, reactors are necessary during pyrolysis process, because it breaks down organic materials using heat (Chen *et al.*, 2021). During the design of the reactor, several variables, including the required pressure, heating temperature, and vapour residence time are considered (Cai *et al.*, 2021). Commonly used reactor configurations for pyrolysis are batch and semi-batch reactors, fixed and fluidised bed reactors, conical sprouting bed reactors, and microwave-assisted technologies (Cai *et al.*, 2021).

**MATERIALS AND METHODS****Methods**

Biomass pyrolysis was performed in an electrically heated fixed bed reactor using 1 mm feedstock. The system was purged with nitrogen to create an inert atmosphere, then heated at 100 °C/min for at least 25 minutes. Condensable gases were collected in ice-cooled traps, and non-condensable gases passed through a water bath. The setup was weighed before and after to calculate yields of char, bio-oil, and gas. The dark-colored bio-oil was transferred to sample bottles, and residual oil was rinsed with ethanol. Proximate analysis was performed to determine the raw material on moisture content, volatile matter content, ash percentage and the percentage of fixed carbon. While the characterization of the elements (ultimate analysis) was also conducted to determine the percentage of

carbon, hydrogen, nitrogen, sulphur and oxygen in the raw material. During this analysis, the percentage of carbon, nitrogen, and sulphur was done while that of hydrogen and oxygen was obtained by calculation (Sengar *et al.*, 2012). Thermal gravimetric analysis/Differential Thermal Analysis (TGA/DTA) also was conducted to get information for the thermal decomposition of palm fronds and coconut fronds; thus, the temperature operation of pyrolysis process could be decided. The thermal stability data were collected on a PerkinElmer TGA 4000 made in Netherlands. The temperature was swept from 30 °C to 950 °C for samples of 4.209 mg for coconut frond and 5.226 mg for oil palm frond. The samples were placed in an aluminum pan at a heating rate of 10.00 °C/min under nitrogen atmosphere. Fourier Transform Infrared Spectroscopy (FTIR) also was conducted on the bio-oil to get functional groups and chemical bonds. The FTIR spectra were recorded in the range of 4000–400 cm<sup>-1</sup> using a Nicolet iS10 and a Perkin Elmer 3000 MX spectrometer. Samples were prepared by mixing a small amount of the material with KBr, grinding it into a fine powder in an agate mortar, and pressing it into pellets under 7 tons of pressure for analysis. The bio-oil samples from the oil palm frond and coconut frond were characterized by Gas Chromatography - Mass Spectrometry using a Perkin Elmer Turbo Mass Spectrophotometer (Norwalk, CT06859, and USA) which includes a Perkin Elmer Auto sampler XLGC. The column used was the Perkin Elmer Elite-5 capillary column measuring 30 m x 0.25 mm with a film thickness of 0.25 mm composed of 95 % Dimethyl polysiloxane. The carrier gas used was helium at a flow rate of 0.5ml/min. 1µl sample injection volume was utilized.

## RESULTS AND DISCUSSION

### Thermogravimetric analysis of Oil palm frond (OPF)

Fig 3.1a and 3.2b show the TGA and DTG curves for OPF pyrolyzed at a heating rate of 10.00°C/min.

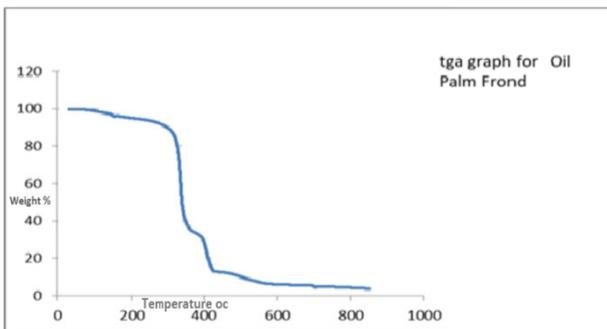


Fig.3.1a. TGA thermogram for OPF pyrolyzed at a heating rate of 10.00°C/min

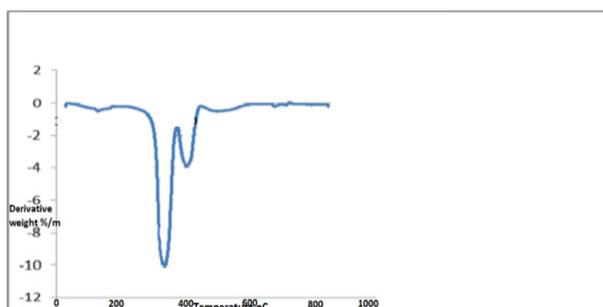


Fig. 3.1b. DTG for OPF pyrolyzed at a heating rate of 10.00°C/min

In figure 3.1a of the TGA curve results shows a gradual weight loss of between room temperature and 300 °C, with moisture evaporation occurring below 150 °C and decomposition of hemicellulose and volatiles continuing up to 300 °C. A major weight loss of 74.67% occurred between 300.22 and 420.24 °C, which marks the primary devolatilization phase, where carbon and volatiles were released. The DTG curve in Figure 3.1b shows two distinct peaks, indicating two major decomposition stages of the oil palm fronds (OPF), corresponding to the thermal breakdown of hemicellulose, cellulose, and lignin. These findings align with results reported by Rotliwala and Parikh (2011).

### Thermogravimetric analysis of Coconut frond (CF)

Figures 3.2a and 3.2b show the TGA curves CF pyrolyzed at a heating rate of 10.00°C/min.

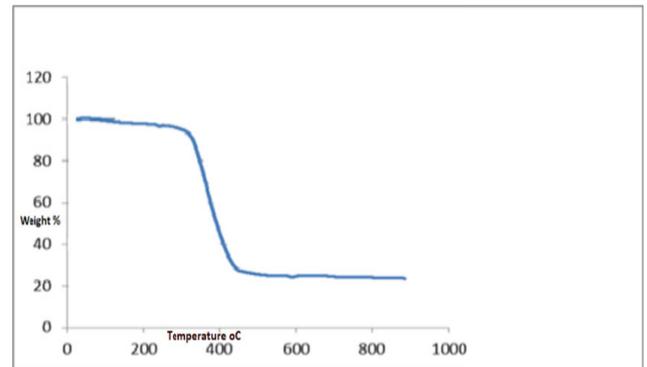


Fig. 3.2a. TGA thermogram for CF pyrolyzed at a heating rate of 10.00°C/min

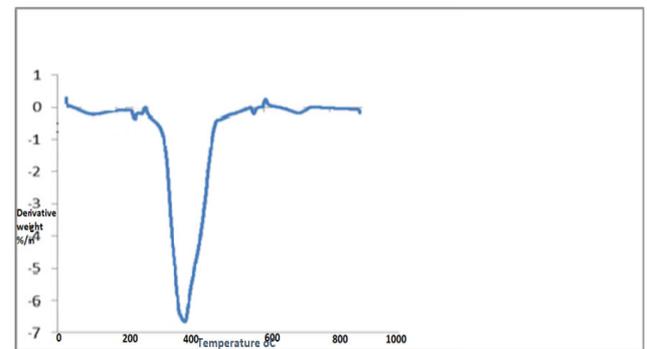


Fig: 3.2b. DTG for CF pyrolyzed at a heating rate of 10.00°C/min

In Figure 3.2a of the TGA curve, it shows a gradual weight loss below 100 °C and up to 300.21 °C, leading to a total mass loss of 95.163 wt%. The initial loss below 150 °C is due to moisture evaporation, while the major loss up to 300 °C is attributed to hemicellulose decomposition and volatile release. Primary devolatilization occurs during this stage. By the end of pyrolysis 23.46 wt% char remained, consistent with Fan *et al.* (2017), who linked higher char yields to increased lignin content in coconut shell. The DTG curve in Figure 3.2b shows moisture loss around 180 °C and a notable peak at around 580 °C, indicating a lignin breakdown and ash transformation taking place. Beyond 600 °C, the weight loss curve flattens with no distinct peaks, thereby suggesting that 600 °C is the optimal pyrolysis temperature for converting coconut frond (CF) into biochar.

**Table 3.1. Main Characteristics of the Oil Palm Frond (OPF) and coconut frond (CF)**

Characteristics	OPF	CF
Proximate analysis (wt. % dry basis)		
Ash	2.85	3.58
Fixed carbon	0.10	0.13
Moisture content	8.08	10.00
Volatile matter	88.97	86.29
Ultimate analysis (wt. % dry basis)		
Carbon	39.32	38.72
Hydrogen	7.44	7.11
Nitrogen	0.027	0.356
Sulphur	0.25	0.82
Oxygen	52.97	53.04
Calorific value (MJ kg <sup>-1</sup> )	29.81	28.93

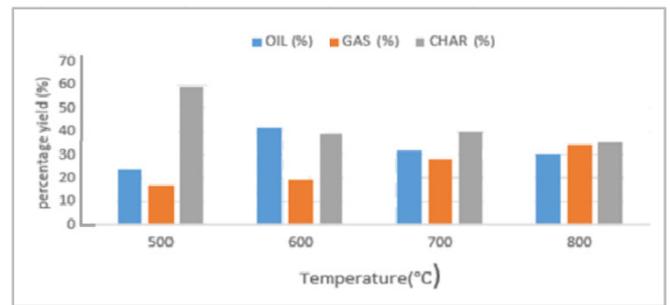
The results of proximate and ultimate analysis are shown in Table 3.1 From this result, according to Prakash & Sheeba (2016).low nitrogen content present in the oil palm frond and coconut fronds depict that they are environmentally friendly energy sources. It reduces the NO<sub>x</sub> emissions during combustion. The moisture content of OPF and CF was 8.08 wt% and 10.00 wt% respectively. These feedstock samples obviously meet the requirements for pyrolysis, which involves feedstocks with moisture content beneath 15% (Parthasarathy *et al.*, 2022). On a dry basis, volatile matter content was high for both OPF (88.97 wt%) and CF (86.29 wt%), which shows a strong suitability for thermal decomposition and bio-oil production and also a high amount of volatile matter indicates a low ignition temperature (Khan *et al.*, 2019). The Fixed carbon content was also low at 0.10 wt% for OPF and 0.13 wt% for CF, while ash content measured 2.85 wt% and 3.58 wt% for OPF and CF, respectively. As a result of the ash-content being less than 7%, it indicates that they may have good heating properties (Parthasarathy *et al.*, 2022). In these results, the low fixed carbon levels indicate minimal solid char residue, and the variations are linked to biomass composition, which are typically in the order of lignin > hemicellulose > cellulose (Asadullah *et al.*, 2008).

The calorific values of OPF and CF were 29.81 MJ/kg and 28.93 MJ/kg, respectively and these values are influenced by the biomass's ash content, moisture, and elemental composition. The Ultimate analysis shows that OPF contained 39.32 wt% carbon, 7.44 wt% hydrogen, 0.027 wt% nitrogen, 0.250 wt% sulfur, and 52.97 wt% oxygen while for CF, it contained 38.72 wt% carbon, 7.11 wt% hydrogen, 0.356 wt% nitrogen, 0.82 wt% sulfur, and 53.04 wt% oxygen. A higher carbon and hydrogen levels are associated with increased heating value (Demirbas, 2004; Jenkins, 1998), while higher oxygen content lowers it and makes bio-oil less suitable for blending with conventional hydrocarbon fuels (Sensoz *et al.*, 2006). Also, the high oxygen content in bio-oil also lead to in stability because oxygenated compounds cause chemical aging, increased viscosity and potential phase separation, especially when water content exceeds 30 wt% (Lehto *et al.*, 2013). This research reinforces the need for upgrading or refining bio-oils before use in the energy systems.

### Effect of Temperature on Pyrolysis Products Yield

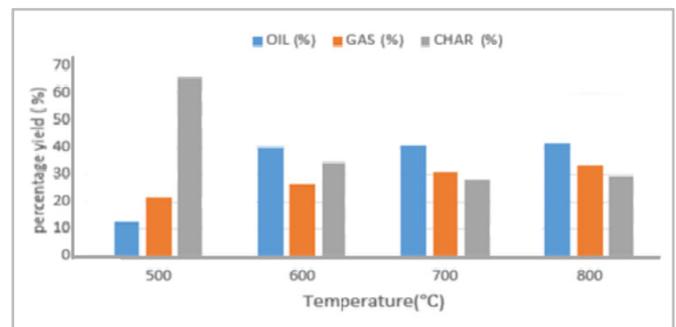
The effect of temperature on pyrolysis products yield of oil palm frond (OPF) and coconut frond (CF) are shown in Figs 3.3 and 3.4

### Oil palm frond (OPF)

**Fig 3.3. Effect of temperature on pyrolysis products yield of oil palm frond (OPF)**

In this, the results show that at temperature of 500 °C, it produces the highest char of (59.36 wt%). As temperature increased to 600 °C, char yield significantly dropped to 38.89 wt%, with a high yield bio-oil yield at 41.65 wt%. However, as the temperature rose to 700 °C, it leads to a decrease in bio-oil yield of 31.64 wt%, and this occurs likely due to thermal cracking of the bio-oil into gas. The char yield decreases with a low yield of 35.22 wt% at 800 °C, while gas yield increased steadily from 16.88 wt% at 500 °C to 34.29 wt% at 800 °C. This process leads to a breakdown of pyrolysis vapors and char at higher temperatures. Overall, the results deduced that 600 °C is the optimal temperature for maximizing bio-oil production.

### Coconut frond (CF)

**Fig (3.4) Effect of temperature on pyrolysis products yield of coconut frond (CF)**

In this, at temperature of 500 °C, there was an increase in the yield of char at 65.76 wt%. As the temperature increased from 500 to 600 °C, the bio-oil yield increased from 12.54 wt% to 39.83 wt%, and slightly increases to 40.61 wt% at 700 °C and peaked at 41.24 wt% at 800 °C. The increase in the yield of bio-oil is because of biomass breakdown. However, increase in temperature leads to bio-oil cracking and increase in gas production. There is a decrease in char yield significantly with an decrease in temperature from 65.76 wt% at 500 °C to 28.28 wt% at 700 °C due to high primary and secondary decomposition of biomass and char. The gas yield steadily increased from 21.7 wt% at 500 °C to 33.45 wt% at 800 °C, likely due to secondary reactions of pyrolysis vapors and char, thereby producing more non-condensable gases.

### Effect of Time

Effect of time on pyrolysis products yield of oil palm frond (OPF) and coconut frond (CF) are shown in Figs 3.5 and 3.6

## Oil palm frond (OPF)

In this result, at a time of 25 minutes, decomposition was slow, and bio-oil was the main product, with a yield of 37.47 wt%. As the time increased from 25 to 75 minutes, bio-oil yield increased slightly from 34.92 wt% to 37.47 wt%, peaking at 75 minutes but decreased to 30.07 wt% in 100 minutes. Char yield increased from 16.34 wt% at 25 minutes to 35.5 wt% at 50 minutes then decreased to 31.59 wt% by 100 minutes. The gas yield increased from 28.74 wt% at 25 minutes to 38.34 wt% at 100 minutes. This result shows that extended pyrolysis time increases the yield of gas while reducing the yield in bio-oil.

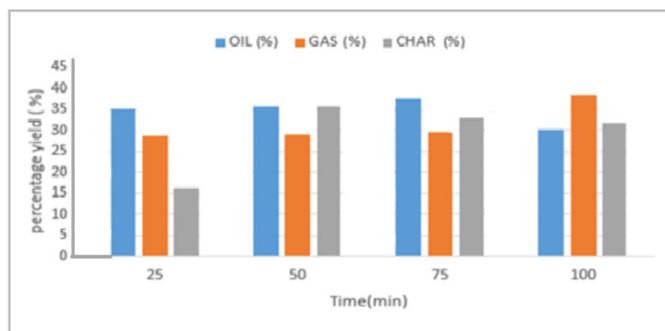


Fig 3.5. Effect of time on pyrolysis products yield of oil palm frond (OPF)

## Coconut frond (CP)

The results show at a time of 25 minutes, decomposition was slow, and char was the main product with a yield of 42.29 wt%. The yield in bio-oil increases from 32.01 wt% at 25 minutes to peak of 41.32 wt% at 75 minutes and later dropped to 28.13 wt% at 100 minutes while char yield decreased from 42.29 wt% at 25 minutes to 26.3 wt% at 50 minutes and increases slightly from 28.26 wt% at 75 minutes and then decreased again to 27.18 wt% at 100 minutes. The gas yield increases from 25.7 wt% at 25 minutes to 32.31 wt% at 50 minutes, decreased to 24.52 wt% at 75 minutes, and then sharply increased to 44.69 wt% at 100 minutes. These changes in the result suggest that increase in pyrolysis time increases the yield of bio-oil but later increases gas yield through secondary reactions.

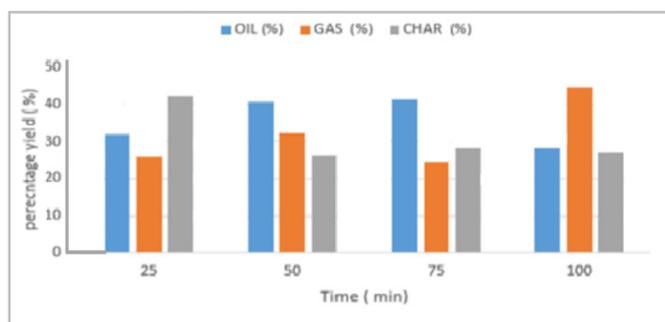


Fig 3.6. Effect of time on pyrolysis products yield of Coconut frond (CF)

## Properties of Bio-Oil of Coconut Frond and Oil Palm Frond

The physicochemical properties and ultimate analysis of bio-oil from CF and OPF are shown in Table 3.2.

Table 3.2. Properties of Bio-Oil of Coconut Frond and Oil Palm Frond

Property	CF	OPF
Physicochemical property		
pH	3.4	3.4
Density (g/cm <sup>3</sup> )	1.054	1.035
Viscosity (cp)	9.6	8.8
Water content/moisture (wt %)	95.5	95.81
Volatile matter (wt %)	4.4	4.05
Ash content (wt.%)	0.09	0.09
Calorific value (MJ/kg)	1.45902	1.35504
Ultimate analysis		
Carbon	23.14	19.15
Nitrogen	0.013	0.038
Sulphur	0.1	0.14
Hydrogen	28.67	29.09
Oxygen	48.09	51.63

Every feedstock yielded a dark brown liquid bio-oil. For CF, and OPF, the oil's pH values are 3.4, and 3.4, respectively. Oil acidity is a sign that a significant number of organic acids may be present in the oil (Abu and Titiloye, 2013; Fan *et al.*, 2014). Furthermore, according to Kan *et al.* (2016), the oil's acidity suggests that lignin and hemicellulose components were broken down during pyrolysis to create acid chemicals. The water content of the oil was 95.50 wt% for CF, and 95.81 wt. % for OPF. This was likely due to dehydration during pyrolysis reaction (Zhang *et al.*, 2007). The density was 1.054 g/cm<sup>3</sup> for CF, and 1.035 g/cm<sup>3</sup> for OPF which are higher than that of gasoline (0.723 g/cm<sup>3</sup>) and diesel (0.838g/cm<sup>3</sup>) fuels. Viscosity was found to be 9.6 cp for CF, and 8.8 cp for OPF. The ash content of the bio-oil was 0.09 wt% for CF and 0.09 wt% for OPF. The ash level of the bio-oils may have been influenced by water- or oil-soluble metallic compounds, or by foreign particles like rust and grime. According to Asadullah *et al.* (2008), the primary metals in ash for biomass pyrolysis liquid include Ca, K, Si, Mg, Fe, S, Al, P, Na, and Zn. Ash content is the leftover left over from burning a fuel. Liquid fuels with high ash content, such bio-oil, can cause injector and pump damage. Ash contains alkali metals, which cause deposits and corrosion in combustion equipment (Oasmaa and Peacock, 2001). Forty-odd weight percent of the bio-oil is volatile stuff for CF and five percent for OPF. The ultimate analysis showed that bio-oil has 23.14 wt% carbon for CF and 19.15 wt% for OPF. Hydrogen was 28.67 wt% in CF and 29.09 wt% in OPF. Nitrogen was 0.013 wt% in CF and 0.038 wt% in OPF. Sulphur was 0.10 wt% for CF and 0.14 wt.% for OPF while that of oxygen is 48.09 wt% for CF and 51.63 wt.% for OPF. The oil's low levels of sulphur and nitrogen imply that bio-oil made from biomass leftovers could be a clean energy source. For CF and OPF, the oil has a higher heating value of 1.459 MJ/kg and 1.355 MJ/kg. These figures drop in comparison to the higher heating values of 45 MJ/kg for diesel and roughly 47 MJ/kg for petrol. This is explained by the oil's high water and oxygen concentrations, which calls for upgrading.

## Fourier Transform Infrared Spectroscopy analysis

**FTIR for Coconut frond (CF):** The FTIR spectrum of the bio-oil from Coconut frond is shown in Fig 3.7

From Fig 3.7The presence of alcohol and phenol is indicated by the peaks at 3,338 cm<sup>-1</sup> regions, which correspond to O-H stretching vibrations of the hydrogen-bonded hydroxyl (OH) groups of cellulose and absorbed water (Fahma *et al.*, 2010).

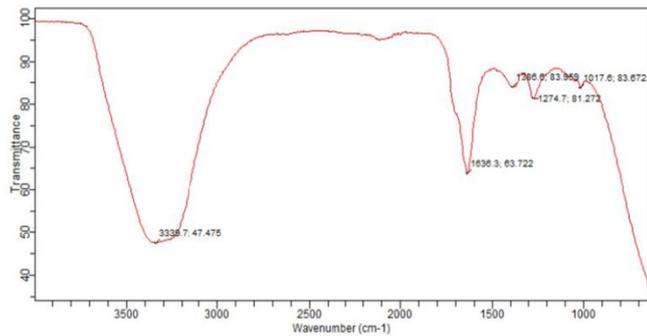


Fig 3.7. FTIR for Coconut frond (CF)

The peak at  $1638\text{ cm}^{-1}$ , which indicates the existence of alkene, revealed the C=C stretching vibrations of lignin. The C-H deformation vibrations at peak  $1380\text{ cm}^{-1}$  suggest the presence of alkanes. The stretching vibrations of C-O bonds from a carbonyl component (such as alcohols, esters, carboxylic acids, or ether) are responsible for the peaks at  $1274\text{ cm}^{-1}$ . The peak at  $1071\text{ cm}^{-1}$  attributed to C-O stretching or C-OH bending indicates the presence of alcohol.

**FTIR for Oil palm frond (OPF):** The FTIR spectrum of the bio-oil from Oil palm frond is shown in Fig 3.8.

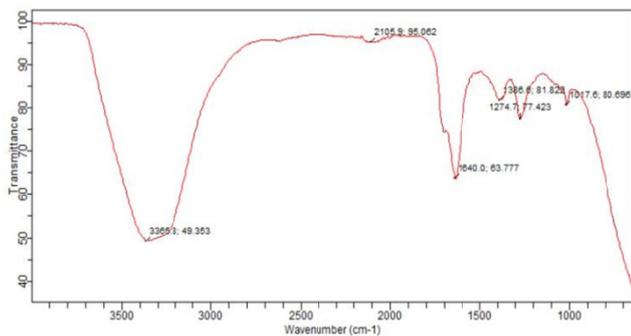


Fig 3.8. FTIR for Oil palm frond (OPF)

Fig 3.8 shows the presence of alcohol and phenol as indicated by the peak at  $3,365\text{ cm}^{-1}$  region, which corresponds to O-H stretching vibrations of the hydrogen-bonded hydroxyl (OH) groups of cellulose and absorbed water (Fahma *et al.*, 2010). The C=C stretching vibrations of lignin were indicated by the peaks at  $1640\text{ cm}^{-1}$  representing the presence of alkene. Alkanes can be detected by the C-H deformation vibrations at peak  $1380\text{ cm}^{-1}$ . The stretching vibrations of C-O bonds from a carbonyl component (such as alcohols, esters, carboxylic acids, or ether) are responsible for the peaks at  $1274\text{ cm}^{-1}$ , while the peak  $2105\text{ cm}^{-1}$  is related to C=C=O (ketones) and indicate the presence of ketenes. The peaks at  $1071\text{ cm}^{-1}$  attributed to C-OH indicate the presence of alcohol.

**GC-MS analysis of Bio-Oil from Coconut frond (CF):** The major chemical composition present in bio-oil is shown in Table 3.3.

In Table 3.3, the coconut frond GC-MS showed that 2-ethylacridine was more dominant in the bio-oil (area percent, 41.98 %) followed by 13-octadecenoic acid, methyl ester (area percent, 34.93 %) and octasiloxane (area percent, 23.09 %). There were high nitrogenated compounds observed in the bio-oil, which is attributed to high protein content in the feedstock biomass. In Manikandan *et al.*, (2019) the results showed that 2-Ethylacridine have (41.98%) which corresponds to that of this research. According to Wang *et al.* (2017), the two main products made from hemicellulose are acetic acid and 2-furfural.

Figure 3.9 displays the bio-oil from the coconut frond GC-MS Chromatograms.

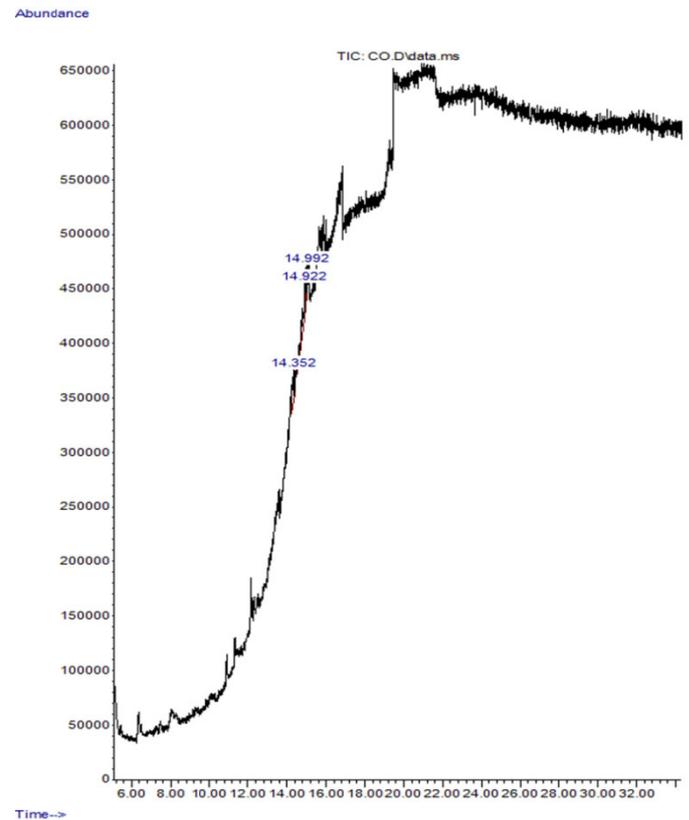


Fig. 3.9. GC-MS chromatogram of Bio-Oil from Coconut frond at temperature of  $700\text{ }^{\circ}\text{C}$

**GC-MS analysis of Bio-Oil from Oil palm frond (OPF):** The major chemical composition present in the bio-oil is shown in Table 3.4.

In Table 3.4, the oil palm frond GC-MS showed that beta. -D-Glucopyranose, 1,6-anhydro- was more dominant in the bio-oil (area percent, 40.39 %) followed by phenol, 2,6-dimethoxy- (area percent, 33.16 %). Abnisa *et al.*, 2013 stated that there is high presence of starch and cellulose as well as a high percentage of phenol present in an oil palm bio-oil can leads to thermal degradation of the palm fronds.

Table 3.3. Major Chemical composition of Bio-Oil from Coconut frond at temperature of  $700\text{ }^{\circ}\text{C}$

Header	PK	RT (min)	Area %	Library/ID	Ref	CAS	Qual
1	1	14.3525	34.9254	13-Octadecenoic acid, methyl ester	155738	056554-47-3	44
2	2	14.9218	41.9821	2-Ethylacridine	71643	055751-83-2	60
3	3	14.9918	23.0924	Octasiloxane, 1,1,3,3,5,5,7,7,9,9,11,11,13,13,15,15-hexadecamethyl-	272253	019095-24-0	58

Table 3.4. Major Chemical composition of Bio-Oil from Oil palm frond at temperature of 700 °C

Header	PK	RT (min)	Area %	Library/ID	Ref	CAS	Qual
1	1	6.3496	33.1568	Phenol, 2,6-dimethoxy-	28298	000091-10-1	97
2	2	7.2325	14.475	3,5-Dimethoxy-4-hydroxytoluene	38872	006638-05-7	87
3	3	8.0453	40.3934	. beta.-D-Glucopyranose, 1,6-anhydro-	33655	000498-07-7	53
4	4	13.9173	0.4561	2-Ethylacridine	71643	055751-83-2	47
5	5	14.5312	9.3818	Trichothec-9-en-4-ol, 7,8:12,13-diepoxy-, 2-butenate, [4. beta. (Z),7. beta.,8. beta.]-	190064	021284-11-7	42
6	6	14.6293	2.1369	Octasiloxane, 1,1,3,3,5,5,7,7,9,9,11,11,13,13,15,15-hexadecamethyl-	272253	019095-24-0	49

Wang *et al.*, 2017 added that a high lignin content that breaks down into phenolic compounds has an impact on a bio-oil's high phenolic compound concentration.

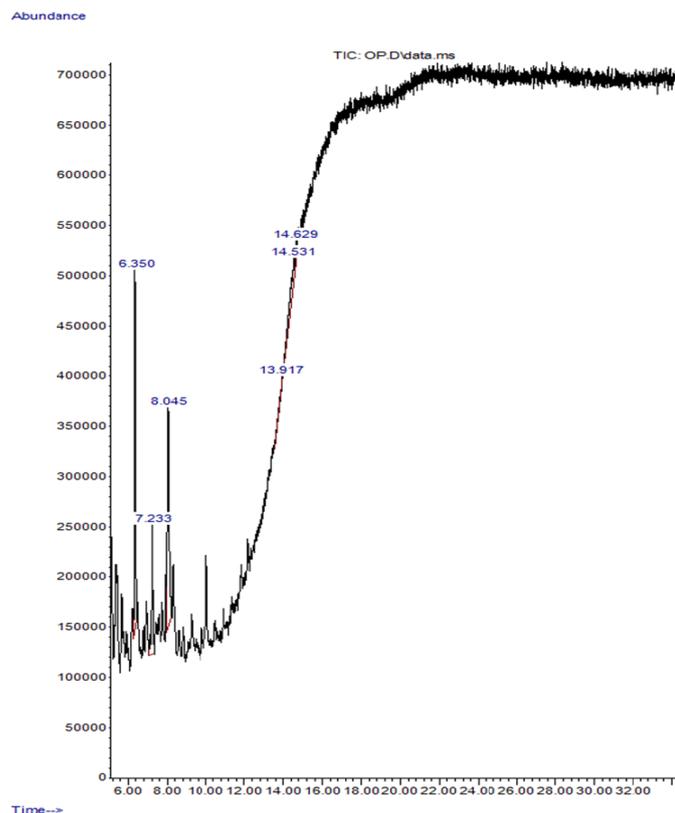


Fig. 3.10. GC-MS chromatogram of Bio-Oil from Oil palm frond at temperature of 700 °C

## Conclusion

Pyrolysis of oil palm frond and coconut frond were conducted in a fixed bed reactor. The products obtained were bio-oil, char and gas. The investigation on the impact of time on products also revealed that the best times to make bio-oil were 75 mins compared to petrol of 100 mins and char for palm fronds and coconut fronds was 50 mins. For oil palm frond, the ideal bio-oil yield was obtained at a pyrolysis temperature of 600 °C. However, for coconut fronds, it took 75 mins at 800 °C. The highest yield of char product was achieved by pyrolyzing coconut fronds for 25 mins at 500°C, and oil palm for 30 minutes. The optimum gas yield was obtained at the temperature of 800 °C at a time of 100 mins. The calorific values of the biomass were high (28.93 MJ/kg–30.16 MJ/kg). The amount shows that the raw materials' energy content was appropriate for usage as a source of energy. A biomass's reduced calorific value (LCV) is caused by the raw materials' high moisture content. This suggests that during burning, moisture absorbs some of the combustion energy to evaporate water, reducing the amount of net useable energy produced.

Also, the study indicates that bio-oil is acidic, having a pH value of 3.3-3.4 indicates that it is unstable for direct use for fuel and requires pre-treatment or upgrading. The FTIR examination of all the functional groups found indicates that oxygen predominates in the chemical component. Three different chemical components were found in coconut frond bio-oil and six in oil palm frond bio-oil according to the GC-MS analysis. It was noted that the bio-oil's chemical composition corresponds to a mixture of several aromatic and oxygenated molecules, such as aldehydes, phenols, ketones, and carboxylic acids. The pyrolysis oil at this stage is best suitable as chemical feedstock.

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