



# Production and Characterization of Bio-oil Derived from Empty Fruit Bunch (EFB) using Fast Pyrolysis

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## Authors' contributions

*This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.*

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## ABSTRACT

This study uses GC-MS and FTIR analyses to investigate the chemical composition of bio-oil derived from the pyrolysis of Empty Fruit Bunches (EFB) at 500 °C. The heating rate was 50-100 °C/min, and the time residual was around 1 min. The GC-MS results showed a lot of different compounds. The leading group was phenol derivatives, but phenols, esters, acids, and other oxygenated organic compounds were also found. The presence of lighter and heavier organic molecules, ranging from C<sub>1</sub> to C<sub>44</sub>, further emphasizes the bio-oil's complex nature. FTIR analysis provided additional insights into the functional groups present in the bio-oil, revealing strong O–H stretching vibrations indicative of phenols and alcohols, C–H stretching and bending vibrations corresponding to alkanes, C=C stretching vibrations from conjugated alkenes, and N–O stretching

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vibrations suggesting nitro compounds. Carbonyl-containing groups such as alcohols, carboxylic acids, ethers, and esters were also detected. There were 3 main products: bio-oil 50- 70 %, biochar 15-25 %, and syngas 10-20 %. The high oxygen content and diverse functional groups in the bio-oil indicate its potential for use in various industrial applications, including fuel production and chemical synthesis. However, the presence of oxygenated compounds suggests that further refining may be necessary to enhance its properties for use as a biofuel. These findings provide a comprehensive understanding of the bio-oils composition and potential applications.

**Keywords:** Biomass; pyrolysis; bio-oil; climate change; greenhouse gases.

## 1. INTRODUCTION

A secure environment is crucial for all living organisms, including humans, animals, vegetation, and other aquatic and land species. Environmental regulation has grown as a significant mechanism for resolving ecological challenges. It has gained extensive application in the economic operations of nations across the globe [1]. Still, releasing massive amounts of pollutants and greenhouse gases (GHG) causes negative environmental impacts that can change the ecosystem [2]. Mitigating greenhouse gas (GHG) emissions is crucial for maintaining a healthy environment and improving human life. The emissions and concentrations of GHGs, including carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), nitrous oxide (N<sub>2</sub>O), and water vapor, are steadily rising due to rapid urbanization and industrialization [3]. In contrast, the same pollutants, such as air pollutants or greenhouse gases (GHG), can dissolve in the water of the oceans or the seas or the water of the rivers and lead to other forms of pollutants that have negative impacts on the biodiversity and ecosystem of the land and air and the marine, riverine environment [4]. Moreover, the ecosystem is at high risk due to the discharge of hazardous compounds into the environment; more important field of this risk is global warming and the problems of climate change and an increase in the average global temperature by more than 1.0 C; this risk mainly due to industrial operations which have high growth since the period of the industrial revolution until now, especially waste streams and gas emissions [5]. Given the environmental challenges posed by the excessive use of fossil fuels such as coal, crude oil, and natural gas, biomass presents a promising alternative. Its versatility allows for conversion into various products, including biofuels, bioenergy, bioproducts, and biochemical [6].

Biomass refers to organic matter derived from plant or animal tissue, including agricultural and

forest resources, municipal solid waste, industrial waste, and other waste materials, which can be used as energy sources [7]. Biomass is among the alternative fuel sources that are expected to replace conventional fuels shortly. Using alternative fuels like biomass can decrease the concentration of greenhouse gases produced by human activities and minimize agricultural waste [8]. Biomass can be converted into biofuel by physical, thermochemical, and biochemical processes. Densification, crushing, heat, and pressure are the physical usage techniques to convert the biomass into biofuel [9]. Thermochemical biomass conversion contains various methods, including combustion, gasification, and pyrolysis. The biochemical process converts biomass into clean energy by using enzymes and microorganisms to produce energy. In the thermochemical process, a high amount of heat energy and catalyst is used to decompose biomass. A potential source of biomass is derived from oil palm wastes since the quantity of fresh fruit bunches reaches a million tonnes annually. Oil palm production consistently produces empty fruit bunches (EFB), representing 20-30% of the total fresh fruit bunches. EFB typically contains a volatile matter content of 60-80% and has a higher heating value (HHV) ranging from 15 to 19 MJ/kg. This indicates a significant potential for energy and chemical production [10].

Pyrolysis is a thermo-chemical decomposition process in which, in the absence of oxygen, organic material, or biomass, is converted into a carbon-rich solid and a volatile matter of heating [11]. Biochar or char is the solid product, and the volatile fraction of this process is partially condensed to a liquid fraction [4]. Pyrolysis increases the energy density of biomass and can be performed on a small scale or in distant locations [12]. Additionally, pyrolysis shows several advantages over fossil fuels, as it generates fuels with lower sulfur and nitrogen emissions [13]. The main product of pyrolysis is bio-oil, which possesses a higher heating value

compared to the original feedstock and can be further transformed into various chemical compounds [14]. This study aims to contribute to producing and understanding EFB's potential as an alternative to fossil fuels, particularly bio-oil, from fast pyrolysis.

## 2. METHODOLOGY

### 2.1 Materials and Methods

Materials: The raw material used in this research is an empty fruit bunch (EFB) collected from a palm oil mill in Klang, Selangor, Malaysia. The raw material EFB has an inherent particle size of 12– 28 mm, with a bulk density of about 670 kg/m<sup>3</sup>.

### 2.2 Experimental Set- UP for Production of Bio-oil from the fast Pyrolysis Process

Fig. 1 shows that the reactor was made of stainless steel, with a height of 50 cm and a diameter of 10 cm. About 200 g of the biomass was the feedstock, placed in a batch reactor. This reactor is vertically positioned, and N<sub>2</sub> gas was introduced inside the reactor at an injection amount/speed of 200 ml/min from the bottom, passing through the top of the reactor. The heating rate was 50-100° °C/min, and the time residual was around 1 min. The injection of

nitrogen replaced the air from the reactor and allowed the pyrolysis reaction to occur under inert conditions. The pyrolysis of the raw material took about 30 minutes and gradually, after 30 minutes, collected the bio-oil. The vapour and gases formed from the pyrolysis of the biomass inside the reactor flowed out along with N<sub>2</sub> from the top of the reactor. The mixture of gas was passed through two condensers. The first condenser was cooled using dry ice, by which the vapour temperature was reduced to around 60 °C, and the circulation of iced water reduced the temperature of the second condenser, where it was cooled to around 5 °C. No vapour was seen to have escaped from the second condenser [10].

### 2.3 Analytical Analysis

#### 2.3.1 Fourier Transform Infrared Spectroscopy (FTIR)

FTIR instrument indicates that the bio-oil consisted of oxygenated organic compounds; the functional group of samples was analyzed and measured by FTIR spectroscopy. This instrument also investigates and applies the structural changes of bio-oil as a function of different sample preparations (pre-treatment process). This research will perform FTIR using a Perkin Elmer Spectrum GX FTIR spectrometer with a wavelength of 4000– 400 cm<sup>-1</sup>.



Fig. 1. Pyrolysis reactor for production of bio-oil

### 2.3.2 Gas Chromatography-Mass Spectroscopy (GCMS)

GC-MS (Auto System XL GC/Turbo Mass MS, Perkin Elmer) with a quadruple detector and a DB-1MS capillary column (30 m × 0.25 mm inner diameter × 0.25 μm thickness) is used to test the bio-oil composition. As for the carrier gas, helium (UHP) is used at a constant flow of 1.2 mL/min. The primary temperature of the oven temperature program was 40°C and the heating continued for 4 min, rising by 5°C/min to 250°C, then continued to 10 min. The bio-oil chemical composition was tested using the GC-MS (Auto System XL GC/Turbo Mass MS, Perkin Elmer) by a quadruple detector and a DB-1MS capillary column (30 m × 0.25 mm inner diameter × 0.25 μm thickness). Helium (UHP) was used as the carrier gas with a constant 1.2 mL/min flow. The primary temperature of the oven temperature program was set at 40°C and continued for 4 min, rising by 5°C/min to 250°C, which continued for another 10 min. The injector temperature was 250°C and the volume of the injected sample (10% of bio-oil in chloroform) was 1 μL. Electron ionization (EI) was used in the MS, and standard mass spectra with 70 eV ionization energy were recorded by scanning, which ranged from 0 to 1200 amu. On the other hand. The computer recording matches the mass spectra that were performed using the NIST98 and WILEY7.0 library, and the retention time of known species injected in the chromatographic column was used to identify the peaks.

### 3. RESULTS AND DISCUSSION

As indicated in Table 1, the GC-MS analysis results revealed that phenol derivatives are the most significant group of compounds in the bio-

oil. Phenolic compounds are common byproducts of pyrolysis of lignocellulosic biomass. They are very interesting because they could be used to make chemicals, fuels, and materials. These phenolic compounds can be precursors for producing polymers, resins, and other high-value chemicals.

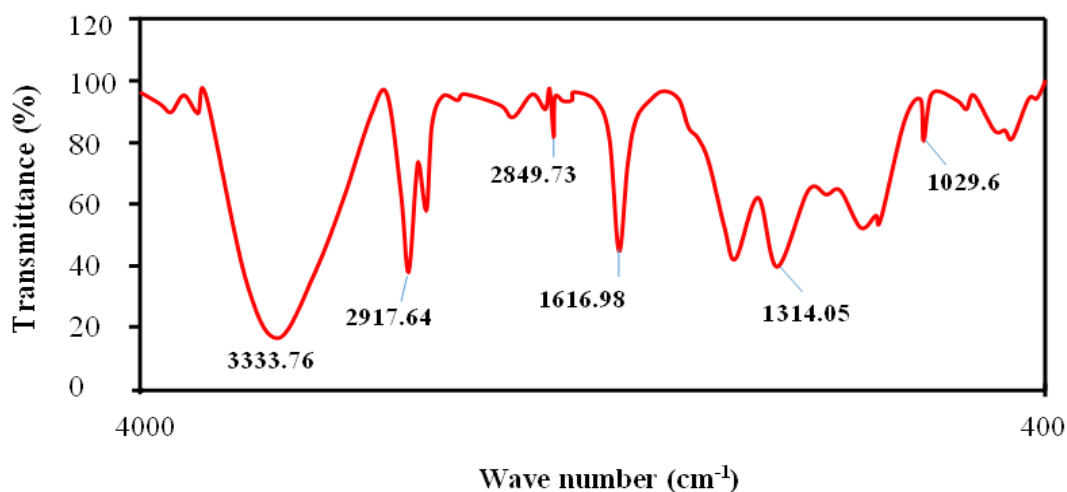
However, the bio-oil derived from EFB is not limited to phenol derivatives. The analysis also showed the presence of various other organic compounds, many of which are oxygenated. The study found that bio-oils often contain oxygenated compounds like phenol, 4-methyl, allophonic acid, phenyl ester, and others. This is because biomass has much oxygen in it. These oxygenated compounds can significantly affect bio-oil properties, such as acidity, stability, and energy content.

The wide range of compounds, from C<sub>1</sub> to C<sub>44</sub>, indicates that the bio-oil contains both lighter and heavier organic molecules. The lighter compounds often contribute to the bio-oil's volatility and lower boiling points, while the heavier compounds contribute to its higher viscosity and energy density. This mixture of compounds, ranging from small molecules to more complex ones, reflects the diverse chemical nature of the bio-oil.

Bio-oil may also have a lot of lignin-derived products because they contain heavier organic compounds. This is because lignin usually breaks down into more significant, complex molecules during pyrolysis, unlike cellulose and hemicellulose. This complex mixture of compounds makes bio-oil a challenging material to refine and upgrade, but it also offers opportunities for producing a wide range of valuable chemicals.

**Table 1. Possible chemical compounds of EFB Bio-oil**

Possible Chemical Compounds	Molecular formula	Peak Area, %
2-Pyrrolidinone	C <sub>4</sub> H <sub>7</sub> NO	1.05
1,3,5-Trioxane	C <sub>3</sub> H <sub>6</sub> O <sub>3</sub>	8.50
2-Furanmethanol	C <sub>4</sub> H <sub>5</sub> OCHO	6.84
2-Cyclopenten-1-one, 2-methyl	C <sub>6</sub> H <sub>8</sub> O	8.48
Pyridine, 3-methoxy	C <sub>6</sub> H <sub>7</sub> NO	6.59
Phenol, 2-methyl	C <sub>7</sub> H <sub>8</sub> O	6.02
Butan-2-one, 3-(2-ethynyl) (isopropyl)amino	C <sub>10</sub> H <sub>17</sub> NO	4.71



**Fig. 2. FTIR analysis of EFB bio-oil**

The FTIR analysis of bio-oil derived from the pyrolysis of EFB at 500 °C reveals a complex mixture of oxygenated organic compounds, consistent with the bio-oil's composition identified through GC-MS analysis. Vital functional groups detected include O–H stretching vibrations (3333.56-3400 cm<sup>-1</sup>) indicating phenols and alcohols, C–H stretching vibrations (2917–2850 cm<sup>-1</sup>) corresponding to alkanes, and C=C stretching vibrations (1616–1650 cm<sup>-1</sup>) suggesting the presence of conjugated alkenes. Additionally, N–O stretching vibrations (1502–1314 cm<sup>-1</sup>) point to nitro compounds, while C–H bending vibrations (1466–1470 cm<sup>-1</sup>) further confirm the presence of alkanes. The C–O vibrations (1104–1200 cm<sup>-1</sup>) highlight carbonyl compounds like alcohols, carboxylic acids, ethers, and esters. This detailed chemical characterization underscores the bio-oil's potential for diverse applications, from fuel production to chemical synthesis, though its high oxygen content may necessitate further refining for fuel use [15]. Fig. 2 illustrates the FTIR analysis of EFB bio-oil.

#### 4. CONCLUSION

The GC-MS and FTIR analyses of bio-oil derived from EFB pyrolysis at 500 °C reveal a complex mixture of compounds, predominantly oxygenated organic molecules such as phenols, alkanes, alkenes, nitro compounds, and carbonyl-containing species. The high oxygen content and diverse functional groups indicate potential applications in fuel production and chemical synthesis, though further refining may be required to enhance its suitability as a biofuel.

These findings provide a comprehensive understanding of the bio-oil's composition, essential for optimizing its industrial utilization.

#### DISCLAIMER (ARTIFICIAL INTELLIGENCE)

The author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of manuscripts.

#### COMPETING INTERESTS

Authors have declared that no competing interests exist.

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