

Biomass to Biofuel: Sawdust Conversion into Bio-Oil via Pyrolysis

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Received on: October, 2025

Revised and Accepted on: November, 2025

Published on: December, 2025

ABSTRACT

This study investigates the conversion of sawdust into liquid fuel via pyrolysis. The bio-oil derived from sawdust pyrolysis was analyzed using gas chromatography-mass spectrometry (GC-MS). The results reveal a complex mixture of organic compounds, including phenolic compounds, ketones, aldehydes, and fatty acids. Phenolic compounds, such as phenol-2-methoxy- and Phenol-2,6-dimethyl are the most abundant group in the bio-oil, likely derived from the lignin component of the sawdust. The presence of these compounds suggests that the bio-oil could be used as a potential feedstock for the production of chemicals and fuels. Further studies are needed to optimize the pyrolysis process and upgrade the bio-oil for practical applications. This study provides valuable insights into the composition of bio-oil derived from sawdust pyrolysis and its potential applications.

Keywords: Biomass conversion, pyrolysis, sawdust, Bio-oil production, GC-MS characterization

1.0 INTRODUCTION

The increasing global demand for energy, coupled with the need to reduce greenhouse gas emissions and promote sustainable development, has led to a growing interest in renewable energy sources. One promising approach is the thermal decomposition of organic materials through pyrolysis, a process that converts waste biomass into valuable products, including liquids, gases, and char, in the absence of oxygen (Repsol, 2025). Pyrolysis has gained significant attention in recent years due to its potential to generate energy from waste biomass, reduce environmental pollution, and promote sustainable development. Pyrolysis involves heating organic materials to high temperatures, typically between 300°C to 900°C, in an inert atmosphere. This process breaks down the complex molecular structures of biomass into simpler compounds, resulting in the production of bio-oil, bio-gas, and bio-char (Safarian *et al.*, 2021). The proportions of these products depend on the temperature, residence time, and type of biomass used. For instance, fast pyrolysis, which involves rapid heating rates and short residence times, tends to produce more bio-oil, while slow pyrolysis produces more bio-char (Ungureanu *et al.*, 2025). Pyrolysis offers several advantages over other thermochemical conversion technologies. It has low capital investment requirements, produces a liquid product that can be easily transported and converted into fuels and valuable chemicals, and generates energy from waste biomass (Kabir *et al.*, 2022). Additionally, pyrolysis can help reduce greenhouse gas emissions by utilizing waste biomass that would otherwise decompose and release methane, a potent greenhouse gas. The

products of pyrolysis can be utilized in various industries, including energy, agriculture, and chemical production.

The bio-oil produced from pyrolysis can be used as a fuel or feedstock for the production of chemicals, such as phenols, aldehydes, and ketones (Ungureanu *et al.*, 2025). Bio-gas, which is primarily composed of carbon monoxide, hydrogen, and methane, can be used as a fuel or feedstock for the production of chemicals, such as methanol and ammonia (Maitlo *et al.*, 2022). Bio-char, a solid product of pyrolysis, can be used as a soil amendment to improve soil fertility and sequester carbon (Varkolu *et al.*, 2025).

This study aims at pyrolyzing sawdust waste and investigating the chemical composition of the pyrolyzed oil. The objective is to generate energy from waste biomass, reduce greenhouse gas emissions, and promote sustainable development. By exploring the potential of pyrolysis to convert waste biomass into valuable products, this study can contribute to the development of sustainable energy solutions and waste management strategies.

2.0 MATERIALS AND METHODS

2.1. Methods

2.1.1 Sample Collection and Preparation

The sawdust waste sample was collected in a polyethylene bag at random from the vicinity of wood sellers at Kara market, Sokoto and transported to the laboratory for analysis. The collected sample was air-dried for 24 hours before the pyrolysis experiment.

2.1.2 Pyrolysis of Sawdust

About 3 kg of sawdust waste was carefully loaded into a locally fabricated pyrolysis reactor (pyrolyzer) with a 10-liter volume. The pyrolysis reaction was conducted at a temperature of 500°C and atmospheric pressure for 1 hour. The reactor was designed to ensure optimal heat transfer and minimize heat loss during the pyrolysis process. The pyrolysis reaction was initiated by heating the sawdust waste in the absence of oxygen, which led to the breakdown of complex molecular structures into simpler compounds. The pyrolyzed oil from sawdust started to drop from the reactor outlet, which was equipped with a condenser, after 25 minutes. No catalyst was used in the reaction, and the pyrolyzed oil was collected at the reactor outlet from the beginning of pyrolysis to the end. The total quantity of pyrolyzed oil, char, and pyrolyzed gas was calculated after the reaction was completed. The pyrolyzed oil was collected and stored in a sealed container for further analysis. The char was also collected and weighed, while the pyrolyzed gas was estimated based on the mass balance of the reaction. The composition of the pyrolyzed oil was investigated using a GCMS-QP2010SE Gas Chromatography Mass

Spectrophotometer (Shimadzu) equipped with a 30m×0.32mm, Rxi-624 Sil MS capillary column (Restek Corp.). This advanced analytical technique allowed for the identification and quantification of various chemical compounds present in the pyrolyzed oil. The GC-MS analysis provided valuable insights into the chemical composition of the pyrolyzed oil, which can be used to determine its potential applications and suitability for various industrial processes.

3.0 RESULTS AND DISCUSSION

The GC-MS chromatogram (Figure 1) illustrates the complex composition of the pyrolyzed oil derived from sawdust waste, while Table 1 provides a detailed breakdown of the compounds present. According to the Gas Chromatography Mass Spectrometer (GC-MS) analysis, a total of 27 organic compounds were identified in the oil. These findings highlight the diverse range of chemical constituents present in the pyrolyzed oil, which can be attributed to the decomposition of lignocellulosic materials in the sawdust waste during the pyrolysis process.

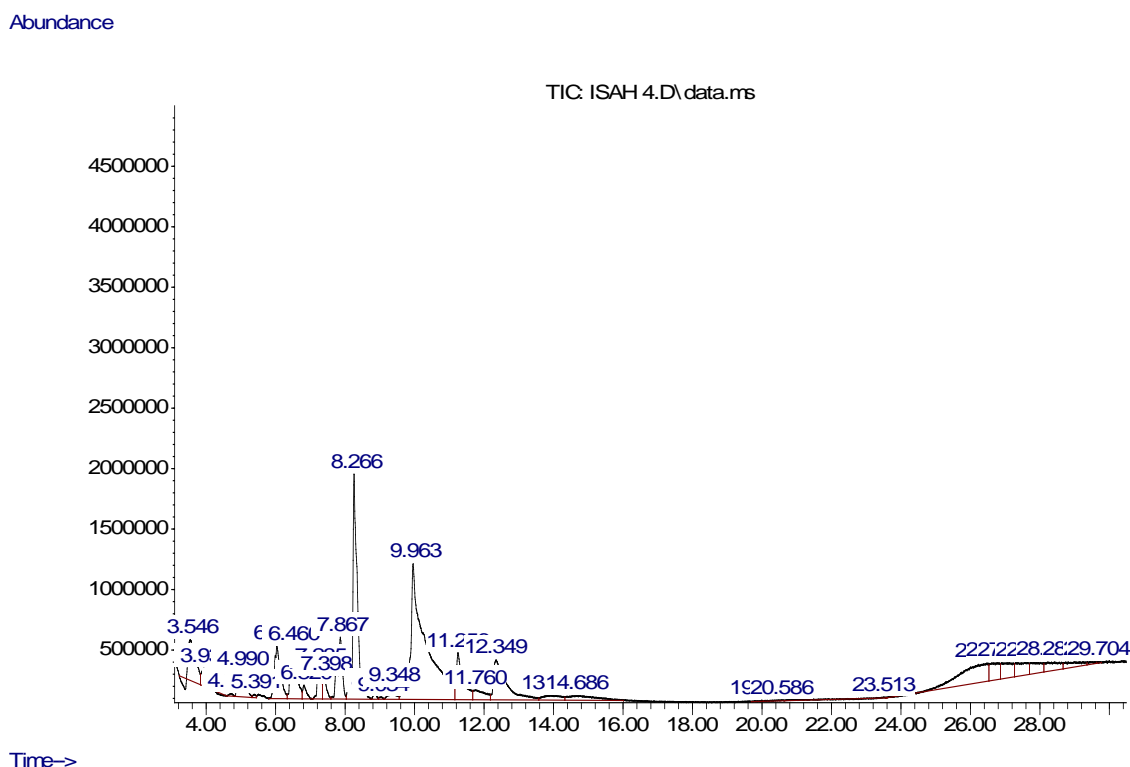


Figure 1: Chromatogram of the GC-MS analysis of pyrolyzed oil from sawdust

The thermal degradation of lignocellulosic biomass through pyrolysis leads to the formation of bio-oil, a complex mixture of oxygenated organic compounds.

These compounds are of significant interest due to their applications in a wide array of chemical, pharmaceutical, and industrial processes. A gas chromatography-mass

spectrometry (GC-MS) analysis (from Table 1) of bio-oil revealed the presence of several key compounds, each with varying relative abundance as indicated by their percent area. The chemical constituents and their potential industrial or pharmacological applications are discussed in detail below, supported by recent literature.

Furfural is an aromatic aldehyde derived from agricultural residues such as corncobs, oat hulls, and sugarcane bagasse. It is formed via the acid-catalyzed dehydration of pentoses (C₅ sugars), primarily xylose. In this study, furfural constituted 3.85% of the bio-oil composition, indicating a significant presence. As reported by Koita *et al.* (2022), furfural serves as an important platform chemical and solvent in organic synthesis. It is a precursor to furfuryl alcohol, which is widely used in the production of foundry resins, adhesives, and fiberglass-reinforced plastics. Moreover,

furfural is gaining recognition in green chemistry as it can replace petroleum-based chemicals in a number of industrial applications. Due to its potential for conversion into fuels and chemicals such as furan, tetrahydrofuran, and levulinic acid, furfural is considered a cornerstone in the biorefinery concept (Xu *et al.*, 2022). With a 1.13% area, 2,5-dimethylfuran (DMF) is a promising bio-based compound with several noteworthy properties. Structurally, it is a methylated derivative of furan and has attracted interest for its potential as an energy-dense biofuel, boasting higher energy content than ethanol. Beyond its fuel applications, DMF also exhibits potential in pharmaceutical and biomedical research. Studies suggest its utility in antifungal treatments and in probing human urinary metabolism. The compound's stability and volatility also make it useful in organic synthesis and as a precursor for the synthesis of various fine chemicals (Li *et al.*, 2020).

Table 1: Results of the Peak No., Retention time, % area and compound present in the pyrolyzed oil

Peak No.	Retention time	% Area	Name of compound	Qual.
1	3.55	3.85	Furfural	58
2	3.93	1.13	Furan,2,5-dimethyl	52
3	4.72	0.12	Beta-Dglucopyranoside, methyl-3	43
4	4.99	2.59	Cyclopropane, tetramethyl methylene	64
5	5.39	0.13	Oxa-cycloudec-8-ene-2,7-dione	47
6	6.043	4.09	2-furancartoxaldehyde-5-methyl	81
7	6.46	4.37	Phenol	90
8	6.82	0.69	Tetrahydrofurfurylchloride	53
9	7.39	1.10	4-Octyne	52
10	7.23	1.55	1,2-cyclopetanedione-methyl	94
11	7.86	1.10	Acetophenome	93
12	8.26	13.95	Phenol-2-methoxy	97
13	8.85	0.27	2-cyclopentan-1-one,3-ethyl-2-hydroxy	70
14	9.34	0.10	2-penten-4-yn-tol,3-methyl, (e)	50
15	9.48	0.86	Phenol-2,5-dimethyl	95
16	11.56	4.13	Phenol-4-ethyl-2-methyl	76
17	11.60	1.54	Benzoic acid	93
18	12.49	6.76	Phenol-2,6-dimethyl	98
19	13.89	1.10	3,3-methyl-2,2-thienyl acrylic acid	41
20	14.86	1.74	1,4-benzendicarboxylicacid,dime	38
21	19.92	0.04	Pyrimidine-2,4,6-trione-1-benzyl	30
22	20.86	0.11	Trans-2,3-methylenedioxy-6-methyl	35
23	23.13	0.16	1,4-bis-trimethylsilylbenzene	43
24	26.92	2.19	Methytris(trimethylsiloxy) silane)	50
25	27.28	2.38	Cyclotrisloxane, hexanemethyl	53
26	28.37	1.64	Arsenous acid, tris (trimethylsilyl) ester	52
27	28.99	1.16	Tetrasiloxane, decamethyl	50

Although present in minor quantities (0.12% area), methyl β -D-glucopyranoside is significant in biomedical and biochemical research. This glycoside is glucose analog and is commonly used to study glucose transport mechanisms in mammalian cells, especially in kidney, liver, and intestinal tissues. Due to its structural similarity to glucose, it serves as a marker for evaluating the efficacy and function of glucose transporter proteins, particularly in disease states such as diabetes and cancer

(Chen *et al.*, 2021). It is also relevant in metabolic labeling experiments and structural studies on carbohydrate-active enzymes. Cyclopropane derivatives are known for their unique ring strain and reactivity. The compound tetramethylmethylene cyclopropane, present with a 2.59% area, possesses intriguing pharmacological properties, particularly as an inhalation anesthetic. Cyclopropane and its derivatives have historically been used as anesthetics due to their rapid onset and offset, low

toxicity, and minimal effects on cardiovascular stability. As highlighted in pharmacological research, substituted cyclopropanes exhibit improved safety profiles and can serve as candidates for the development of next-generation anesthetics (Wang *et al.*, 2023). Moreover, their stability and lipophilicity contribute to their effectiveness in modulating neuronal ion channels.

5-Methylfurfural (5-MF), contributing 4.09% to the total GC-MS area, is a well-known product of the Maillard reaction, which occurs between amino acids and reducing sugars during thermal processing of food and biomass. This compound has dual relevance, in the food industry, it is a flavor-enhancing agent, while in biochemical contexts, it serves as an intermediate in the synthesis of furan-based compounds. It is also associated with human metabolism, particularly in the oxidative degradation pathways of sugars. The role of 5-MF in advanced glycation end products (AGEs) has been linked to aging and diabetes, highlighting the need for further toxicological assessments (Sadowska-Bartosz *et al.*, 2020). Phenol, a simple aromatic alcohol found with a 4.37% area, is a prominent compound in bio-oil derived from lignin degradation. Phenolic compounds such as phenol are known for their antimicrobial properties and are widely used in the pharmaceutical, cosmetic, and fragrance industries. Shasha *et al.* (2023) confirm phenol's relevance in perfume production, where it acts as a fixative or precursor to more complex aromatic compounds. In industrial chemistry, phenol is an essential raw material for manufacturing bisphenol A, caprolactam, and phenolic resins. Additionally, it plays a role in the synthesis of antioxidants and antiseptics. Tetrahydrofurfuryl chloride, representing 0.69% area, is a halogenated furan derivative commonly used as an intermediate in the production of agrochemicals, pharmaceuticals, and rubber additives. This compound serves as a precursor for the synthesis of tetrahydrofurfuryl alcohol, which is used as a solvent in coatings, resins, and cleaning agents. Its structure allows for versatile reactivity, including nucleophilic substitution and ring-opening reactions, making it useful in a wide array of chemical syntheses (Kumar *et al.*, 2022). The alkyne 4-octyne, identified at 1.10%, is less common in biological systems but is noteworthy in industrial and synthetic chemistry. As a terminal alkyne, it can undergo a variety of reactions including hydrogenation, oxidation, and cycloaddition, making it a versatile building block. Baska and Uzun (2019) noted that 4-octyne is utilized in chemical industries for redox reactions and in studies involving molecular conformation and structure due to its linear geometry and electron-rich triple bond. It also plays a role in material science research where alkynes are incorporated into

functional polymers. Present with a 1.55% area, 3-methyl-1,2-cyclopentenedione is a diketone with notable antioxidant properties. Specifically, it has demonstrated the ability to scavenge peroxy nitrite, a reactive nitrogen species that contributes to oxidative stress and cellular damage in inflammatory and neurodegenerative diseases (Bhattacharya *et al.*, 2021). This compound is of interest in drug discovery and biochemical research for its potential in modulating oxidative pathways. Its conjugated dione structure provides electron-withdrawing capabilities, enhancing its reactivity with free radicals. With a 3.76% area, acetophenone is another aromatic compound found in bio-oil. It is widely used as a flavoring agent, fragrance additive, and intermediate in organic synthesis. In the food industry, acetophenone imparts a sweet, almond-like aroma and is commonly added to chewing gum and baked goods. In pharmaceuticals, it is used as a solvent and as a starting material for synthesis of various pharmaceuticals including antihistamines and hypoglycemics (US FDA, 2021). Its relevance also extends to the development of resin cross-linkers and photoinitiators in polymer chemistry. The most abundant compound detected in this analysis, phenol-2-methoxy (also known as guaiacol), accounted for a significant 13.95% of the total area. Guaiacol is a key compound derived from lignin pyrolysis and serves multiple functions. It acts as a natural flavoring agent, a plant metabolite, and a pheromone in some insect species. In medicine, guaiacol is used as an expectorant and antiseptic, and in analytical chemistry, it is a reagent for detecting peroxidase activity. Guaiacol's phenolic structure allows for antioxidant activity, making it a target for nutraceutical and pharmaceutical development (Yang *et al.*, 2019). The findings of this study are consistent with previously reported literature on the pyrolysis of biomass and the composition of bio-oil. The identification of phenolic compounds such as guaiacol and phenol, as well as aldehydes and ketones like furfural and acetophenone, reflects the thermal degradation of lignin, hemicellulose, and cellulose components of biomass. These compounds are not only of academic interest but also carry significant commercial value. The data supports the view that bio-oil can be a renewable source of platform chemicals for diverse

4.0 CONCLUSION

The GC-MS analysis of pyrolyzed oil derived from sawdust waste revealed a complex mixture of chemical compounds with diverse applications. With phenol-2-methoxy- (%area 13.96) and Phenol-2,6-dimethyl (% area 6.76) are the most abundant group among others in the bio-oil, likely derived from the lignin component of the sawdust. These findings highlight the potential of pyrolysis as a viable method for converting waste

biomass into valuable products. It also revealed the significant importance of sawdust pyrolysis in the area of pharmaceutical, medicine, petroleum, cosmetics and industries. The results of this study can contribute to the development of sustainable waste management strategies and renewable energy solutions. By optimizing the pyrolysis process and characterizing the products, this study can provide valuable insights into the potential applications of pyrolysis technology for waste biomass conversion.

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