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Research Article

Investigation on Forestry Wood Wastes: Pyrolysis and Thermal Characteristics of Ficus religiosa for Energy Recovery System

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Pyrolysis is the most important thermochemical process that can be used for the production of biofuel, from wood and wood-based lignocellulosic materials. In this study, bio-oil is produced from the bio-weed named *Ficus religiosa* by the thermal pyrolysis process by utilizing laboratory-scale fluidized bed reactor. This study deals with the production of maximum bio-oil by optimizing process parameters such as process temperature, particle size, and sweep gas flow rate. Further different analytical techniques were used to describe the properties of bio-oil for different applications. Wood and wood barks of *Ficus religiosa* were chosen as the raw material due to their higher volatile content (72.4%). The maximum yield of 47.5 wt% bio-oil was collected at the optimized operating conditions of 450°C temperature, 1.0 mm particle size, and 2.0 m^3/h sweep gas flow rate. Compared with other operating parameters, temperature is observed as the most significant one to determine the product yield. Through chromatographic analysis, it was identified that the bio-oil is found with the variety of chemical compounds including alcohols, alkenes, phenols, saturated fatty acids, and esters.

1. Introduction

The promotion of sustainable energy development has been aided by increased global energy demand with increased greenhouse gas emissions [1]. Wood and biomass materials are taken as promising alternative material for producing fuels and chemicals [2]. These sources are renewable, available abundant, carbon-neutral, and does not compete with food [3]. Since the mid-1970s, when the oil crisis began, numerous efforts were made to convert wastes into fuels and chemicals. To meet country's energy needs, United States, China, India, and other countries are significantly dependent on foreign countries, creating tremendous incentives for the development of renewable energy sources. In 2020, India contributed 4.6% to the global fossil fuel use, placing it third in the world after United States and China. In accordance with the findings of Huber, biomass-derived biofuels are the viable resource for liquid hydrocarbon production for transportation [4], but the economically viable method of producing them has not yet been identified.

Wood and wood-based lignocellulosic materials are the most important sources of renewable energy. It is the feedstock obtained from dedicated crops, forest wastes, and a collection of municipal solid wastes. The energy is recovered directly from wood in the form of either electrical or thermal through combustion and other thermal processes [5]. The management of wastes obtained from wood is critical to raise the sustainability requirements. The wood-based biomass generally consists of wood waste, tree bark, tree trunk, and leaves, and it contains energy obtained by photosynthesis. These wastes can be burned to generate energy or can be processed to produce fuel [6]. The energy from the direct burning of wood and wood products is mostly used for many heating applications, but pyrolysis and gasification allow them to produce more valuable liquid and gaseous combustibles that can be used for other processes. In particular, the pyrolysis has emerged as an effective conversion process of wood-based biomass materials into liquid fuels. When compared to other conversion techniques, pyrolysis yields more liquid products with increased energy contents. It is a thermal breakdown process that produces char, oil, and gaseous compounds due to the breakdown of polymeric chain components without air/oxygen [7]. Pyrolysis oil is generally having higher energy density and is easier to store and transport than conventional diesel oil. Fast or flash pyrolysis is the advanced technique that enhances more liquid oil production than slow pyrolysis [8]. Several articles have been published previously utilizing many biomass materials for the pyrolysis process. Makkawi et al. [9] performed pyrolysis of palm wastes at 525°C and obtained bio-oil production of 38.8 wt%. The bio-oil has calorific value of 20.88 MJ/kg, which is significantly lower than the heating value of softwood bark pyrolysis oil. In another study, Pinto et al. [10] utilized pinewood bark for the pyrolysis process and produced 37 wt% of bio-oil at the optimum temperature of 550°C. Recently, Sakthivel et al. [11] utilized wood wastes of *Calophyllum inophyllum* for pyrolysis. The study utilized various chromatographic techniques to analyse the obtained oil products. The FTIR study on bio-oil showed the presence of C=C, –CH, C=O, and –OH functional groups. Dhanalakshmi and Madhu [12] carried out the research on flash pyrolysis of wood bark of *Azadirachta indica*. The study yielded a maximum of 49.5 wt % pyrolysis oil at 450°C under 1 mm particle size and at 2 m^3/hr N_2 flow rate. Fast pyrolysis of pine and oak wood barks was performed by Ingram et al. [13] at 450°C. The results of this study suggested that the portable auger reactors can be utilized for biofuel production in various sites in forests. This method also allows more efficient transportation of less bulky bio-oil compared with raw wood. In addition to the above studies, some of the studies utilized wood bark for co-pyrolysis experiments. Co-pyrolysis experiments on mixed food wastes with wood bark were conducted by Park et al. [14] in a continuous pyrolysis reactor. The study characterized three pyrolysis products of oil, char, and gas. When food waste and wood bark were combined at a mass ratio of 1 : 1 at 700°C, the maximum yield of H_2 gas and phenolic and polycyclic aromatic hydrocarbon compounds were obtained.

In the above background, the wood and wood bark of *Ficus religiosa* are utilized for the effective conversion of bio-oil products. *Ficus religiosa* is a type of fig tree origin in the Indian subcontinent. It is a huge, dry-season deciduous tree that can grow up to 30 metres in height having a trunk diameter of up to 3 metres. It is indigenous to most of the Indian subcontinent, including Bangladesh, Nepal, Pakistan, and Assam. In India, this tree is marked with religious and medicinal symbols. It is possible to utilize different parts of trees to treat different ailments such as diarrhoea, jaundice, heart-related diseases, and skin allergies. The diverse parts such as stem, bark, fruits, and resins are used in many different ways. The presence of numerous phytoconstituents such as phenolics, sterols, and flavonoids also has been examined for the past ten years [15]. The wood of the tree is used for carpentry work, and their barks are used for cooking purpose. To the best of the author's knowledge, the publications available related to the utilization of wood and wood barks for biofuel production are very minimum and there was no study that has been discussed the use of wood and wood barks of *Ficus religiosa* for energy recovery through pyrolysis process.

Motivated by waste to energy concept and conversion of wood-based materials for value-added fuels and chemicals, this study focused on pyrolysis of mixed wood and wood barks of *Ficus religiosa*. The ultimate goal of this study was to investigate the pyrolysis behaviour of the feedstock under various operating conditions. To obtain the maximum bio-oil products, flash pyrolysis studies are carried out in a laboratory-sized fluidized bed reactor at various temperatures, particle sizes, and sweep gas flow rates. In the end, the complete characterization of the bio-oil products has been carried out using FTIR and GC-MS.

2. Materials and Methods

2.1. Material Collection and Preparation. The materials used for this study are the collection of wood and wood barks collected from newly cut trunks. The trunks were cut from the tree available in the residential area near Vadavalli, Coimbatore, India (11°02′10.5″N 76°54′50.4″E). The materials were cut into small pieces and dried in an open sunlight for 15 days. After drying, the wood pieces are ball-milled and converted into powder form using a ball mill (Emkad–India made). The samples are then sieved to get desired sizes of 0.5, 0.75, 1.0, and 1.25 mm using Test Sieves made by Jayant Scientific Industries, Mumbai, India. To prevent biological degradation, the powdered materials were oven-dried at 60°C for 1 hr using BSSCO BSEX-1401, B.S. Exports, India. Figure 1 shows *Ficus religiosa* tree.

2.2. Characterization Study

2.2.1. Proximate and Ultimate Analysis. The proximate analysis of the feed materials was carried out by the following ASTM protocols. This analysis gives the information about the amount of total volatiles present in the feedstock

Figure 1: *Ficus religiosa* tree.

materials. The elemental analysis of the feed materials and bio-oil is found by utilizing Perkin-Elmer II 2400 CHNS elemental analyzer by the following ASTM D5373 procedure.

2.2.2. Thermogravimetric Analysis. The thermogravimetric study is used to identify the fundamental behaviour of the feed material during pyrolysis. The analysis was carried out using thermogravimetric analyzer (Q500, TA Instrument). About 5 mg of biomass materials was kept in the furnace. The nitrogen gas and air required for the pyrolysis and combustion experiments are provided during the analysis. For analysis, the feedstock was heated to 700°C at the heating rate of 20 °C/min.

2.2.3. FTIR Analysis. A Bruker Optik GmbH Tensor 27 spectrophotometer was employed to get FTIR spectrum of the oil sample. The spectrum was collected between 400 and 4000 cm^{-1} with 4 cm^{-1} resolution. The spectrum for bio-oil was obtained in the reflectance mode after the sample was dispersed on zinc selenide crystal.

2.2.4. GC-MS Analysis. The bio-oil produced under optimized conditions was examined qualitatively using Thermo GC-Trace Ultra Version: 5.0, Thermo MS DSQ II, GC-MS spectroscopy. The obtained results in this study provided a clear image of the chemical compounds present in the sample.

2.2.5. Physical Characterization. To find the suitability for various applications, the physical qualities of the bio-oil were conducted. To determine the suitability as fuel for IC engine applications, the physical qualities of the oil must be considered. Density, kinematic viscosity, flash point, heating value, and pH value are all analysed in accordance with ASTM standards. Prior to the analysis of the oil, the samples are centrifuged at 3000 rpm to separate the organic phase from the aqueous phase.

2.3. Reactor Setup. The flash pyrolysis experiments are conducted using laboratory-scale fluidized bed reactor of height of 1.0 metre and diameter of 50 mm. The outer surface of the reactor is heated electrically, and the heat input is regulated by the PID controller. Five K-type thermocouples are fixed at different locations to measure the temperature. Nitrogen gas is supplied to the reactor at different flow rates in order to get fluidization along with the sand particles. The temperature of the reactor is raised at 10 °C/min till it reaches the desired value. The reactor can be allowed to heat the samples up to 1100°C. A cyclone separator is fitted at the outlet of the reactor to separate expelled char components from the gas products. A condenser is used to condense volatile fractions released during pyrolysis, and it is collected in a separate glass beaker. The emitted non-condensable gases are allowed to escape into the environment. After cooling, the char elements were removed from the reactor and from the cyclone separator. The reactor facilities available in fuel laboratory are utilized for this study. The reactor was the existing one, and it was not specifically designed for this work. The reactor was supplied by Emkad India Ltd. A high accuracy weighing machine is employed to compute the mass of pyrolysis products. The mass of the uncondensable gas products is identified using the remaining material balance. The overall setup used for this study is shown in Figure 2.

3. Results and Discussions

3.1. Feedstock Properties. Table 1 summarises the important elements of the wood and wood bark of *Ficus religiosa.* The studied material is having higher carbon contents (C), moderate oxygen (O) contents, and higher hydrogen (H) contents. The materials are having low nitrogen (N) and sulphur (S) contents. The values of C, H, N, S, and O of the material are 48.1, 6.3, 2.0, 0.4, and 43.2 wt%, respectively. In addition to that, ash in the feed material is quite minimum (5.2 wt%). The presence of oxygen in the material leads to the production of oxygenated volatiles and acidity. The amount of moisture fractions in the feed materials can reduce the conversion efficiency during pyrolysis and also lowers the heating value of the yield products with the aqueous phase. The higher concentration of volatile matter results in increased volatility and reactivity, which is ideal for the synthesis of large volumes of bio-oil [16].

3.2. Thermal Degradation Analysis. Figures 3 and 4 depict the TGA and DTG plot of the *Ficus religiosa* obtained by heating the samples to 700°C at 20°C/min. As identified from TG curves, the thermal breakdown of the biomass samples appears in gradual manner with clear path. At the temperature of around 260°C, the first peak appeared corresponding to the decomposition of hemicellulose. In this stage, the hemicellulose decomposes into volatiles and an intermediate solid further in the secondary reaction, and the intermediate solid particles are decomposed into condensable volatiles and char products [17]. The second peak started to appear at 350°C, which represents the breakdown of cellulose. Because of the overlap between the other two peaks, the peak associated with the decomposition of lignin

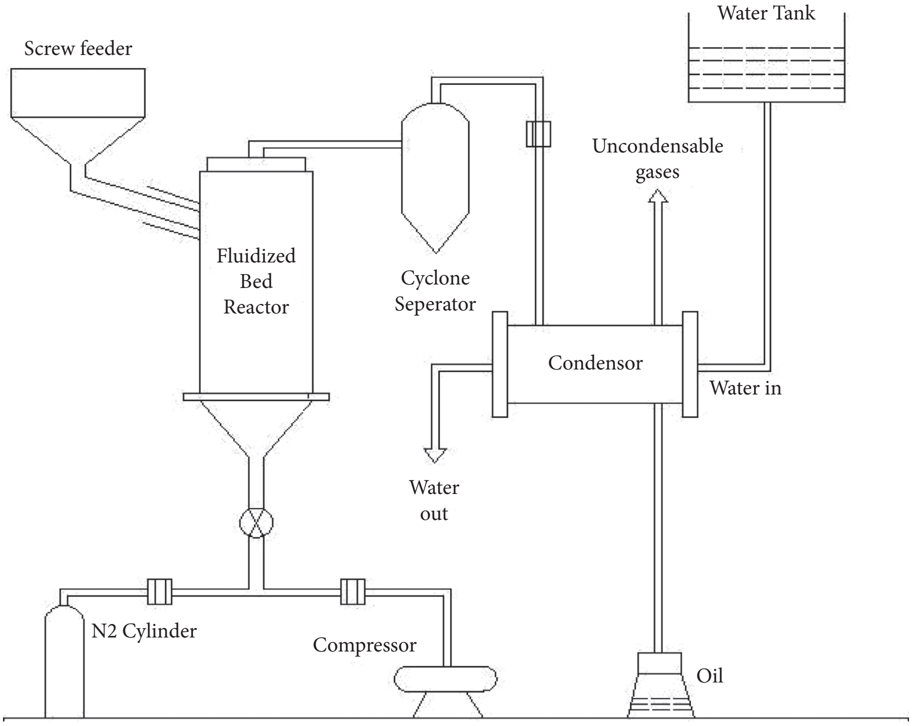

Figure 2: Reactor setup.

Table 1: Properties of feedstock in wt%.

Content	Values
Volatile matter	72.4
Fixed carbon	16.3
Moisture content	6.1
Ash content	5.2
C	48.1
H	6.3
N	2.0
S	0.4
O	43.2
Empirical formula	$CH_{1.56}N_{0.035}O_{0.674}$
Heating value in MJ/kg	17.04

% of O = 100 − (C + H + N + S)%.

is entirely obscured. The decomposition of lignin in the biomass into condensable volatiles and char elements is accomplished by an Arrhenius-type process [18]. It is around 420°C when the thermal breakdown of the entire biomass is practically completed. At elevated temperature, the breakdown of lignin components shows minor weight loss. The utmost weight loss appeared between 370°C and 470°C. The TGA curve shows the char yield of approximately 20 wt%. These results are similar to the previously published literature for rice hulls, olive stones, and sugarcane bagasse [19–21].

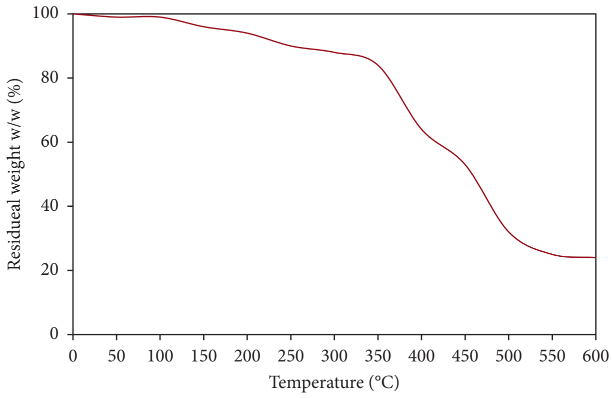

Figure 3: TG analysis of *Ficus religiosa*.

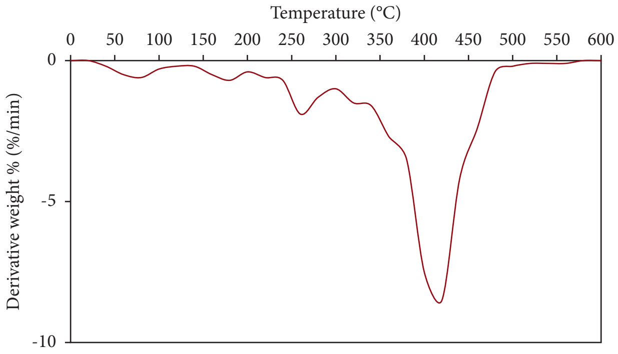

Figure 4: DTG analysis of *Ficus religiosa*.

3.3. Pyrolysis Characteristics

3.3.1. Effect of Temperature. A series of chemical reactions will take place in biomass during pyrolysis. To get primary and intermediate products, it is necessary to decompose the lignocellulosic contents. The heat is supplied to the reactor primarily to break down these constituents. The yields of pyrolysis product distributions at different final temperatures

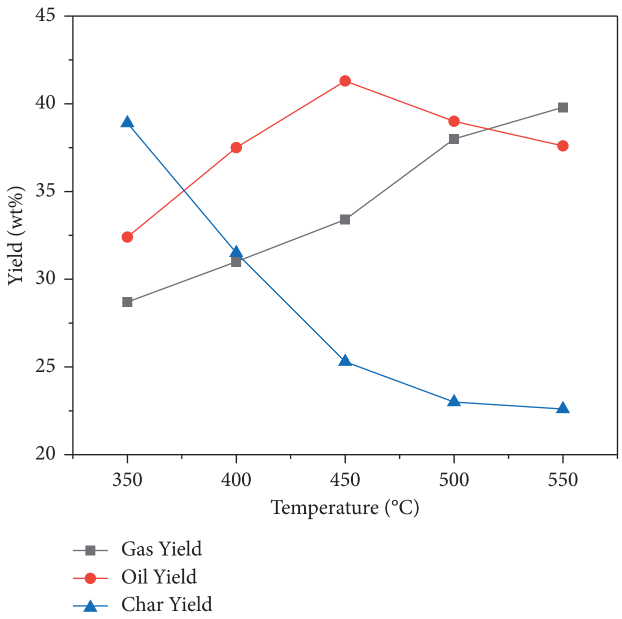

FIGURE 5: Pyrolysis yield under different temperatures.

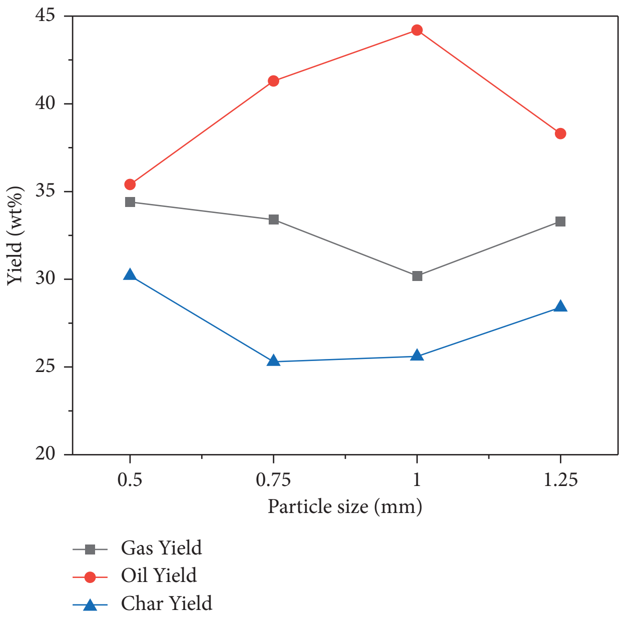

FIGURE 6: Pyrolysis yield under different particle sizes.

are shown in Figure 5. The experiment in this phase was conducted by changing reactor temperature from 350˚C to 550˚C under 0.75 mm particle size and 1.75 m^3/hr N_2 flow rate. Increasing heat input facilitates the breaking of heavy hydrocarbon materials resulting in higher liquid and gaseous products, which negatively affect char production. The yield of char products decreased with increased temperature, because of the primary or secondary breakdown of char particles in the reactor [22]. The char yield decreased from 38.9 to 22.6 wt% with increasing temperature from 350˚C to 550˚C. According to Pütün et al. [23], increasing the reactor temperature from 400 to 700˚C reduced char generation by 10% and 17% for hazelnut shells and sesame stalks, respectively. Choi et al. have also showed a drop in the char products with increased temperature [24]. From the figure, it can be understood that higher char products are achieved at low temperatures. When the amount of heat input provided to the feedstock is increased, it breaks the bonds and enhances the release of condensable volatiles. It is also identified that the yield of pyrolysis oil is gradually enhanced from 32.4 wt% to 37.6 wt% and attained maximum at 450˚C (41.6 wt%). When the temperatures go beyond 450˚C, the production of pyrolysis oil is decreased in the range of 41.3 wt% to 37.6 wt%, which is consistent [25, 26]. The higher carbon conversion into gas at elevated temperature increases the yield of gas continuously from 350˚C to 550˚C. The yield of gas is 28.7 wt% at 350˚C, and it reached 39.8 wt% at 550˚C.

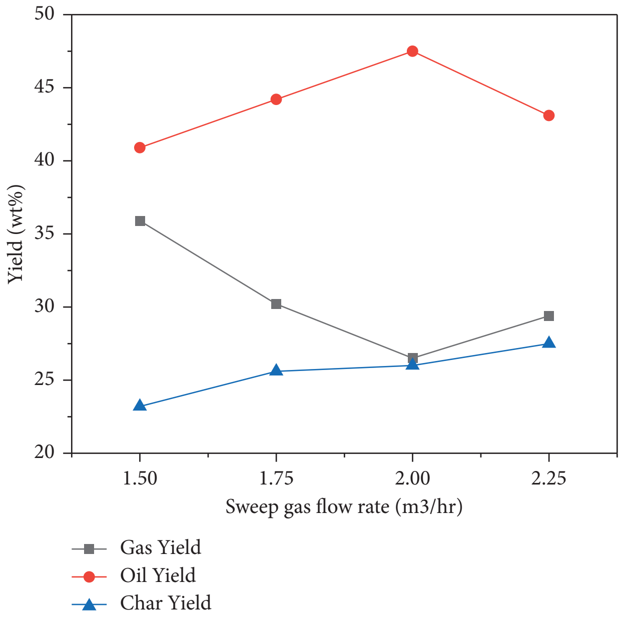

FIGURE 7: Pyrolysis yield under different N_2 flow rates.

3.3.2. Effect of Particle Size. The size of the particle is an important one that should be considered carefully since it might influence the rate of heat transfer. It significantly creates an impact on chemical reaction during the process. The particle size not only affects the pyrolysis reaction, but also affects the pressure drop in the reactor. When the diameter of the particles increases, the distance between the surfaces to its core rises, resulting in poor heat transfer [27]. The increased diameter is generally favoured for the yield of char products. In many previous studies, the yield of products was significantly affected by the size of the particles [28, 29]. The biomass particle size is a very critical one that affects material flow properties. Sowmya Dhanalakshmi and Madhu [8] reported that the production of bio-oil was influenced by the particle size while using neem wood bark. Figure 6 depicts the yield products with respect to particle sizes. From the figure, it is observed from the results that the quantity of oil collection reached a maximum of 44.2 wt% at

Table 2: Properties of the bio-oil.

Properties	Standard	Feedstock materials				
		Ficus religiosa	Pine chips [35]	Lemongrass [36]	Hardwood [37]	Diesel [38]
Density (kg/m^3)	ASTM D445	1005	1200	1010	1220	850
Viscosity (cSt)	ASTM D4052	7.2	28	7.2	13	3.9
pH	ASTM D7946	3.6	2.4	4.1	#	#
Flash point (°C)	ASTM D92	130	95	150	66	57
Elemental compositions (wt%)						
C	ASTM D5373	44.23	45.7	52.14	47.54	86.5
H		8.4	7.0	7.2	7.8	13.2
N		0.81	0.1	0.61	0.5	0.02
S		0.22	0.02	0.1	0.1	0.24
O	By difference	46.34	47.00	39.95	44.06	—
Heating value (MJ/kg)	ASTM D445	18.3	17.2	19.40	18.63	43.6

#—not reported.

1.0 mm particle size. On the other side, the oil yields were reduced to 38.3 wt% at larger particle size. This could be explained by an incomplete process due to the lack of heat transfer [26]. The larger particles do not get properly heated up and end with lower oil yield. According to Figure 6, the char yield is very minimum at 0.75 mm (25.3 wt%). The yield of gas is also a function of particle size. Here, the higher and lower gas products were recorded at the particle size of 0.5 mm (34.4 wt%) and 1.0 mm (30.2 wt%). When the particle size is increased from 1.0 mm to 1.25 mm, the yield of gas is enhanced from 30.2 wt% to 33.3 wt%. The increased gas yield is due to increased particle size in the reactor, which prolongs the residence time of volatile matter leading to secondary cracking reactions.

3.3.3. Effect of Sweeping Gas Flow Rate. Another parameter that affects the product yields is the flow of the sweeping gas. In the fluidized bed pyrolysis of *Ficus religiosa* , a higher amount of vapours is produced, and it should be expelled properly from the reactor or else they may be involved in further reactions, which change the nature of the products. In accordance with the literature, the allowed sweep gas inside the reactor separated the products from the reactor to avoid the secondary reactions and aiding maximize the oil products. Nitrogen is the commonly used carrier gas for pyrolysis experiments due to its better fluidization, inert property, cheap, and availability. It also helps to drain out the reactor towards oxygen free reaction [30]. In this phase, the experiments were conducted at constant temperature of 450°C and at the fixed particle size of 1.0 mm. Figure 7 shows the experimental yields at different N_2 flow rates. At 2.0 m^3/hr, oil product yields reached their maximum value (47.5 wt %). From the results, it can be noted that the N_2 flow significantly creates the impact on residence time of the vapours created during the reaction and prevents secondary reactions [31]. At a higher N_2 flow rate of 2.25 m^3/hr, the gas yield is increased, due to the removal of uncondensed volatiles. In pyrolysis of *Ficus religiosa*, the sweeping gas has not affected much the production of char. The yield of char is 23.2 wt% at 1.5 m^3/hr and 27.5 wt% at 2.25 m^3/hr. Previously, pyrolysis of corncob showed a minor change in char yield from 24.4 to 22.6 wt% when N_2 flow rate was increased from 1.2 to 4.5 L/min [32]. During the Laurel pyrolysis, increasing the N_2 flow rate from 50 to 400 mL/min resulted in a drop in char production from 28.48 wt% to 27.21 wt% [33].

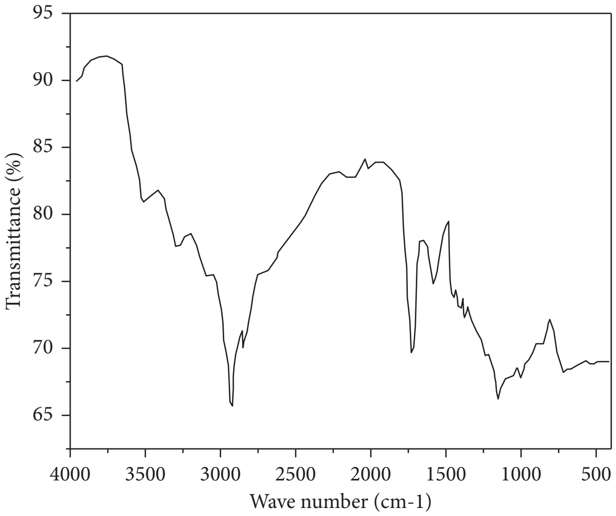

Figure 8: FTIR analysis.

3.4. Characterization Study

3.4.1. Physical Analysis of the Bio-Oil. The basic physical analysis is a very important one since it can be used for any applications based on its physical and chemical properties. The analyses in this study are made on the bio-oil produced at optimum conditions of pyrolysis temperature of 450°C, particle size of 1.0 mm, and sweep gas flow rate of 2.0 m^3/hr. Viscosity, heating value, density, oxygen content, pH value, and density are some of the physical qualities measured in this study and reported in Table 2. The table also compares other pyrolysis oil obtained from different sources. Viscosity is a crucial property of any liquid fuel that determines fluidity. It plays a major role in the design of engines that utilize biofuels [34]. The viscosity of pyrolysis oil varies due to the fact that it is made from a variety of sources.

Table 3: GC-MS analysis of oil obtained at optimized conditions.

RT/Min	Compound name	Molecular name	% area
3.34	Piperidine-2,5-dione	$C_5H_7NO_2$	4.41
4.26	4-Ethyl-2 methoxyphenol	$C_9H_{12}O_2$	1.54
5.42	5-(Benzyloxymethyl)uracil	$C_{12}H_{12}N_2O_3$	0.94
6.31	2-Furanmethanol	$C_5H_6O_2$	0.34
6.96	Phenol, 3,4-dimethyl-	$C_8H_{10}O$	6.58
9.01	Phenol, 2-methoxy-	$C_7H_8O_2$	8.62
12.22	Phenol	C_6H_6O	9.54
13.04	2-Methoxyphenol	$C_7H_8O_2$	3.41
13.56	5-Hydroxymethylfurfural	$C_6H_6O_3$	0.28
14.02	Hexadecanenitrile	$C_{16}H_{31}N$	5.45
14.54	Oleic acid	$C_{18}H_{34}O_2$	0.94
14.69	Pyrrolidine, 1-(1-cyclopenten-1-yl)-	$C_9H_{15}N$	4.44
15.73	2H-Pyran, 2-(2 heptadecynyloxy)tetrahydro-	$C_{22}H_{40}O_2$	3.72
17.43	4,6-Dihydrofuro[3,4-b]furan	$C_6H_6O_2$	1.66
19.77	2-Cyclopenten-1-one	$C_7H_{10}O$	2.60
20.08	1,4-Dimethoxy benzene	$C_8H_{10}O_2$	0.88
21.41	Benzenemethanol, 4-hydroxy	$C_7H_8O_2$	2.04
22.57	Kaempferol	$C_8H_8O_4$	3.44
22.98	9-Octadecenamide	$C_{18}H_{35}NO$	5.32
23.58	4-Methyl-5H-furan-2-one	$C_5H_6O_2$	1.42
23.74	2-Isopropyl-2,5-dihydrofuran	$C_7H_{12}O$	5.20
23.99	Vanillin	$C_8H_8O_3$	3.71
24.09	1H-Imidazole, 1-methyl-4-nitro	$C_4H_5N_3O_2$	0.30
25.16	9-Octadecenoic acid (Z)-,methyl ester	$C_{19}H_{36}O_2$	8.03
27.64	4-Ethyl-2-methoxy phenol	$C_9H_{12}O_2$	1.86
28.43	2,3-Butadiene	$C_4H_6O_2$	0.45
29.10	1,2-Benzendiol	C6H6O	2.55
29.57	Cyclopentanol	$C_5H_{10}O$	3.04
30.42	1-Propyne, 3-iodo-	C_3H_3I	3.23
32.81	Benzhydryl vinyl ether	$C_{15}H_{14}O$	1.59
36.42	1-Methyl-1,3,3-triphenylindan-2-one	$C_{28}H_{22}O$	1.04
37.42	Stigmasterol	$C_{29}H_{48}O$	0.76

Obviously, the viscosity is identified as 7.2 cSt. The higher flash point of 130°C shows that the oil can be stored safely at room temperature. Bio-oil has a density of 1005 kg/m^3, which is denser than mineral diesel (78 kg/m^3). The pH value is shown as low as 3.6 due to acidic chemicals in the sample. When compared to mineral diesel, the heating value is low as 18.3 MJ/kg, which is more enough for the bio-oil obtained from lignocellulosic wastes and it can be improved by further processing.

3.4.2. FTIR Analysis.

Figure 8 shows the FTIR image of bio-oil derived from wood and wood bark of *Ficus religiosa* obtained at optimized maximum yield conditions. The existence of phenolic group is identified by a large stretch at 3500–3200 cm^{-1}. The O-H stretch at 3400–3100 cm^{-1} shows the occurrence of polymeric hydroxyl compound. The C-H stretch obtained at 3000–2850 cm^{-1} represents the alkane compounds in the oil. The C=O stretch found at 1750–1700 cm^{-1} demonstrates the presence of a stable ester group. The N-H bend at 1550–1500 cm^{-1} confirmed amides in the sample. The alcohols and aromatic compounds in bio-oil are represented by stretching vibrations at 1152 cm^{-1} and C-H bending vibration at 710–690 cm^{-1}. The result obtained in this study is consistent with the previous literature [8, 11]. By comparing with previous studies, the oil contains abundant O-containing structures. The functional group of the oil is basically dependent on the elemental compositions of the feedstock materials. The figure also indicates that the oil is complex and has some aromatic compounds, for example, phenols. However, the exact assignment of each band appears to be tough and gives the provision for further study [39].

3.4.3. GC-MS Analysis.

This analysis was done to identify the presence of numerous chemical elements in the oil sample. The sample for this analysis was obtained at optimized maximum yield conditions. The compounds that appeared in this analysis are listed in Table 3. The compounds were significantly identified related to peak area. The analysis revealed the chemical components including alcohols, alkenes, phenols, saturated fatty acids, and esters. In chromatogram, phenolic compounds are observed more than 30%. The degradation of lignin in the wood may be responsible for the increased phenolic content. At the same time, 9-octadecenoic acid (Z)-, methyl ester, hexadecanenitrile, and 9-octadecenamide showed an area percentage of 8.03, 5.45, and 5.32%, respectively. Piperidine-2,5-dione, kaempferol, and stigmasterol identified in the samples are used for medicinal applications, whereas phenol and its derivatives, hexadecanenitrile, oleic acid, vanillin, cyclopentanol, and 2-furanmethanol are used for various chemical processing industries. Apart from that many other chemicals identified in the bio-oil are used as oxidizing agents, reducing agents, food additives, precursors, plasticizer, and perfume additives. Furthermore, several studies also reported the presence of these chemical compounds in various pyrolysis oil [40–42].

4. Conclusion

This study confirms that combination of wood and wood barks of *Ficus religiosa* is valuable raw materials for pyrolysis-based bio-oil production. The most favourable operating conditions for getting higher yield of bio-oil are 450°C temperature, 1.0 mm particle size, and 2.0 m^3/hr sweeping gas flow rate. The yields of liquid oil were in the ranges from 32.4 wt% to 47.5 wt% under these favourable conditions. This study offers a successful method for extracting energy-rich biofuels from *Ficus religiosa* wood. The bio-oil was examined and compared with other pyrolysis oil produced from different wood-based lignocellulosic wastes. The comparison results confirmed that the oil products can be utilized as fuel and have the potential to be employed as a renewable fuel. According to the chemical characterization study, the obtained bio-oils are complex in nature containing a wide range of organic components indicating that they can be used for chemical industries. Further study is also possible to increase the production of char and gas elements by optimizing process parameters with deep product characterization.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this article.

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