

## Research Article

# Thermochemical Recycling of Solid Biomass Materials for Achieving Sustainable Goal: A Complete Characterization Study on Liquid Yield Products

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In order to achieve sustainability goals, biomass is a renewable energy source that lowers emissions of greenhouse gases and other hazardous gases. Biochemical and thermochemical methods are both used to produce bioenergy from biomass. Pyrolysis is an effective thermochemical conversion technique used for the conversion of biomass into energy-rich bio-oil. In this study, the pyrolysis characteristics and bio-oil obtained from the residues of *Ricinus communis* were investigated. The experimental run was designed to analyze the impact of bed temperature on product yield by varying the process temperature from 350°C to 750°C. In this study, a maximum of 46.5 wt% of bio-oil was produced at 500°C. The maximum conversion was recorded at temperatures ranging from 450°C to 550°C. The bio-oil obtained at maximum yield conditions was analyzed using different analytical techniques. The Fourier transform infrared spectroscopy (FT-IR) and gas chromatography and mass spectroscopy (GC-MS) analyses of the bio-oil revealed that the oil has a significant amount of phenol derivatives, oxygenated chemicals, acids, and esters. The physical properties of the bio-oil showed that it is viscous and has a medium heating value compared with commercial fossil fuel.

## 1. Introduction

During the 1970s, the energy crisis in the world raised many questions and uncertainty that could depend on the economy and abundant supply of fossil fuels. Therefore, the scientific work on fossil fuels has focused a lot of attention and effort on developing a more sustainable resource that could replace conventional energy sources. Renewable energy comes from natural sources that replace themselves more quickly. Renewable energy, often known as clean energy, is derived from renewable natural resources or processes. By supplying domestic clean energy sources, bioenergy can help to create a safe and sustainable environment. The production of bioenergy and biomass creates new, decentralized, and diverse income streams that support regional economic growth and employment [1]. Compared with other renewable sources, the development of carbon-neutral and less polluting green fuels from renewable resources like biomass is getting interest more [2]. Biomass is medium energy biological matter obtained directly or indirectly from living or recently living organisms, most commonly plants [3]. Resources made of biomass are abundant in nature. The estimated annual production of biomass around the world is 100 billion tonnes [4]. Almost all the developed countries in the world have initiated the production of market goods from waste raw materials, which is necessary for the transition to a cleaner and sustainable economy. In this row, growing interest is being shown in waste-to-energy activities as a means of improving the sustainability [5].

The handling of waste items is referred to as waste management. It involves the gathering, moving, processing, and disposal of trash. Some important developed waste management systems reduce the strain on landfills by protecting natural resources. Compared with fossil fuels, biofuel production utilizing biomass offers substantial environmental benefits [6]. The emissions of carbon dioxide (CO<sub>2</sub>) during the combustion of petro-diesel are polluting the environment severely. The technologies to reduce CO<sub>2</sub> emissions are limited. It is necessary for plants to grow in order to create biomass feedstock, and this removal of CO<sub>2</sub> from the environment offsets the increase in air pollution due to burning of biomass fuels [7]. Currently, various methods, including biological and thermochemical conversion methods, have been established to transform lignocellulosic feedstock into fuels or value-added chemicals. Biomass feedstock can quickly alter biological conversion, which typically takes more time. Thermochemical conversion is another technique to convert any type of biomass into fuels or chemicals without any constraints [8]. This method is the most convenient and does not require any pre-processing. In the olden days, charcoal was the main product produced by pyrolysis, which was used for heating applications. The primary drawback of this technology was poor energy yields. Therefore, research is being done to develop technology to give the highest output of energy from biomass. Pyrolysis of lignocellulosic material is a somewhat complicated process. Without the presence of air or oxygen, pyrolysis begins by thermally degrading the organic

components. Pyrolysis is generally classified as conventional slow pyrolysis, fast pyrolysis, and flash pyrolysis. Slow pyrolysis is an old technique used for millennia for the production of char. Fast and flash pyrolysis is the advanced technology used for producing more liquid and gas products. Fast pyrolysis offers various appealing qualities, including more bio-oil production. It is simple and efficient, and no feedstocks can be lost during the process. In this process, the majority of the feedstock can be converted into a fuel product. The most suitable pyrolysis process temperature is around 350°C to 550°C, and it can sometimes extend up to 800°C. Due to its prolonged residence period and low heat transfer rates, slow pyrolysis requires additional energy inputs. The fast-pyrolysis process is gaining importance due to the yield of higher liquid fuels. These liquid fuels are easy to transport and store [9]. Fast pyrolysis is a more cost-effective and efficient process compared with the slow pyrolysis process. As pyrolysis technology continues to advance, many reactor designs have been investigated in an effort to improve pyrolysis efficiency and produce maximum bio-oil [10]. The pyrolysis experiments are generally performed by various reactors such as fixed bed, fluidized bed, circulating fluidized bed, vacuum reactor, ablative reactor, vortex reactor, and solar reactor. Fixed bed reactors are widely used for slow pyrolysis processes. Fluidized bed and circulating fluidized bed reactors are used for maximizing liquid products. In an ablative reactor, the feedstock needs not be crushed any more. So, a large particle can be processed with the help of an ablative reactor.

*Ricinus communis* is called the castor oil plant. The plant is native to India, which is grown in gardens and fields as well as in waste areas. In India, almost more than 50% of the tree is found in Gujarat followed by Andhra Pradesh and Rajasthan. The average production of seeds from the tree is 1.2 MT. This production accounts for 75.6% of the world total production. It is a type of perennial flowering plant that belongs to the Euphorbiaceae family. It is a green plant that can reach a height of 10 m. *Ricinus communis* produces seeds, stems, and leaves used for various purposes. At one tonne of waste plant more than 450 kg of seeds, 350 kg of stems and 150 kg of leaves can be extracted [11]. The tree is widely spread over Eastern Africa and India. Previously, Kaur et al. [12] conducted hydrothermal liquefaction experiments on *Ricinus communis* for the conversion of biofuels and hydrocarbons. The study conducted experiments at different temperatures and produced 15.8 wt% of bio-oil at 300°C. The pressed seed cake obtained from this plant was pyrolyzed by Santos et al. [13]. In another study, the residues of *Ricinus communis* were examined for biofuels and chemicals extraction through a pyrolysis process [14]. According to the findings of the research, the residues from the plant can be used for various processes.

The characterization of the bio-oil acquired through the pyrolysis of *Ricinus communis* residues is the focus of the current research activity. Pyrolysis of residues from the tree was carried out in a fluidized bed reactor at different temperatures from 350°C to 750°C. The work is novel in terms of the selection of new materials for pyrolysis. To the knowledge of the authors, no work has been reported using

the selected feedstock. The experiments were carried out to analyze the impact of bed temperature on the yield of the pyrolysis products. The bio-oil acquired at maximum yield point was characterized using different analytical procedures such as FT-IR and GC-MS, and the physical characteristics were also found as per ASTM protocol. The main goal of this study was to analytically check the subtractions of the liquid products and find their suitability for industrial usage. The feed material used for the analysis represents the novelty of the work. Additionally, the bio-oil underwent testing in its raw, unpurified state to find its natural quality.

## 2. Materials and Methods

**2.1. Materials.** The residues of the *Ricinus communis* tree were obtained from the agricultural fields in and around Coimbatore, India. The residues are the combination of leaves, stems, and wood wastes. The sample was ground using a crusher and sieve shaker to get a uniform size of 0.5–0.7 mm. The powdered feedstock was also used for basic analysis. Prior to the experiments, the basic analysis on the sample was conducted to find its suitability for the thermochemical conversion process. The test results are shown in Table 1. These tests were conducted by following appropriate ASTM protocols. From the initial tests, it can be understood that the material has a higher percentage of volatiles. The higher volatiles in the material give confidence for higher volatile release. The lower amount of ash in the material is another positive point for yielding high quality bio-oil. Due to lower ash content, the problems related to burning and corrosion can be minimized. The material has 46.3 wt% C, 5.12 wt% H, 4.01 wt% N, 0.08 wt% S, and 44.4 wt% O. The fixed carbon and oxygen in the sample were found by the difference. The lower amount of sulfur in the material means it is suitable for conversion without emitting hazardous pollutants. The increased amount of oxygen is a disadvantage in the production of high-energy bio-oils such as petroleum diesel.

**2.2. Characterization Methods.** The ultimate analysis of the samples was found by Elementar Vario EL-III (N2410650, PerkinElmer Ltd, US). The thermogravimetric analysis (TGA) of the samples to find the thermal behavior was found by the TGA701 analyzer (LECO Corporation, St. Joe, Michigan, US). TGA was performed to analyze the thermal stability of the feedstock. This analysis was performed in a closed furnace in a nitrogen environment. The material was heated from room temperature to 700°C until it was completely decomposed. The bio-oil produced after the pyrolysis reaction was characterized by the energy-dispersive X-ray analyzer (Model 6587 EDX). The standard redwood viscometer (Neminath Instruments, Ahmedabad, Gujarat), pH meter (Lutron pH meter, Sunshine Instruments, Coimbatore, India), and Pensky-Martens Flash Point apparatus (EIE Instruments, Ahmedabad, India) are used to find its physical properties. The heating value was found by the Parr reactor (model 6772). The functional group of the bio-oil was found by FT-IR and GC-MS analyzers. A FT-IR (BRUKER Optik GmbH, TENSOR 27 Bruker Corporation)

TABLE 1: Characteristics of *Ricinus communis*.

Parameters	Value (wt%)	Standard
Proximate analysis		
Volatile matter	75.3	ASTM D3175
Fixed carbon	11.8	By difference
Moisture content	7.5	ASTM D3173
Ash	5.4	ASTM D3174
Ultimate analysis (ash-free basis)		
Carbon	46.3	ASTM D5373
Hydrogen	5.12	ASTM D5373
Nitrogen	4.01	ASTM D5373
Oxygen	44.4	By difference
Sulfur	0.08	ASTM D5373

spectrometer was used for the FT-IR study. The spectra were captured between 400 and 4000  $\text{cm}^{-1}$ . The organic fraction was subjected to GC-MS studies (Thermo GC-TRACE Ultra ver: 5.0, Thermo MS DSQ II) using DB-35 with a HP-1 capillary column (30 m length, 0.25 mm diameter, and 0.25  $\mu\text{m}$  film thickness). In a splitless mode, 0.3 mL of bio-oil was injected. For carrier gas, helium was employed and supplied at the rate of 1 mL/min. The temperature program for the analysis was as follows: heating from 60°C (holding period- 2 min) to 270°C (5°C/min and holding period-5 min).

**2.3. Apparatus and Procedure.** A fluidized bed reactor of diameter 50 mm was employed in this study for pyrolysis experiments. The equipment consists of a system for feeding fuel samples. The required amount of quartz sand of 0.5 mm was used as a fluidization medium within the reactor. The material feeding system supplies the feedstock into the bed using a variable speed motor at 20 g/min. For fluidization, nitrogen gas was provided at 1.75  $\text{m}^3/\text{hr}$ . The flow rate of the nitrogen was measured by rotameter and controlled by a control valve. The reactor is provided with five thermocouples located at five different positions. The cyclone separator was attached to separate solid particles. Initially, compressed air was used for the fluidization purpose until the material reached the desired temperature. The air and nitrogen were admitted through the distributor plate attached at the bottom of the reactor. Once the reactor reached the desired temperature, the flow of air was stopped and nitrogen was admitted. For better fluidization, 500 grams of sand of 0.5 mm in diameter was kept inside the reactor. The evolved gas coming out of the reactor is sent via the cold water condenser to cool. Due to the condensation process, the bio-oil was collected. The condensed bio-oil is then stored in a separate vessel for additional analysis. In this study, the yield at different temperature was analyzed by conducting pyrolysis experiments at different temperatures from 350°C to 750°C. The maximum yield condition was identified and set for additional bio-oil production. Each experimental run was conducted up to 45 min until complete volatilization. After conducting each experiment, the reactor and cyclone separator were cleaned. The produced bio-oil and char were physically weighed using an electronic balancing machine. Remaining material balance was used to determine the release of gaseous fraction at each run.

### 3. Results and Discussion

**3.1. Thermogravimetric Analysis.** TGA is an analytical technique used to evaluate the thermal stability and the percentage of volatile components in a material. This analysis was performed by observing the weight changes. The TGA/DTG analysis of *Ricinus communis* residue is shown in Figure 1. The heating of the material was done at the heating rate of 10 K/min. The results show thermal degradation behavior of the material occurred at three different zones, such as initial moisture removal, active zone, and passive zone. The evaporation of moisture and light volatiles occurred in the first stage of the pyrolysis experiment, which started at a temperature of 30°C and extended until it reached 120°C [15]. The initial moisture loss tends to the weight loss of the material up to 11.0 wt% [16]. The decomposition of the material initiated at 75°C and sustained up to 550°C with major weight loss. This is called major pyrolysis zone where the decomposition of hemicellulose and cellulose occurs with minor lignin decomposition [17]. During maximum devolatilization, maximum of condensable volatiles was released. Very minimal mass loss is seen in the third zone, primarily between 550°C and 700°C, which is likely owing to the decomposition of carbonaceous in the residues. The DTG curve made obvious the breakdown of biomass components at various temperatures. The breakdown of hemicellulose is represented by the first shoulder obtained at temperature, whereas the breakdown of cellulose in the material is represented by the next shoulder. The degradation of lignin occurs in the tailing portion, often referred to as passive pyrolysis, which operates between 160°C and 700°C. Char is formed as a byproduct of passive pyrolysis [18].

**3.2. Effect of Temperature on Product Yield.** Figure 2 displays the product yields produced by pyrolyzing *Ricinus communis* residue at different temperatures. The temperature of the bed has a considerable impact on the yields and its characteristics [19]. The product of interest from traditional slow pyrolysis is higher charcoal content, whereas the production of higher bio-oil is the interest from fast pyrolysis [20]. The yields of bio-oil products increased in general as the bed temperature increases. The production of bio-oil varies from 18.3 wt% to 46.5 wt%. The production of bio-oil has gone up to 46.5 wt% at 500°C. In this analysis, up to 250°C of bed temperature, there was no bio-oil obtained. A little drop of bio-oil was collected at 350°C. Temperatures below 400°C encourage the production of char products. Below 400°C, the heat transfer to the biomass is sluggish, related to the reaction kinetics [21]. Therefore, the yield of pyrolysis products is very close to the heat carrier capacity of the biomass. After 450°C, the heat transfer was enhanced to release more volatiles from the reactor. The higher temperature inside the bed breaks the heat transfer resistance and helps to achieve complete decomposition. From 350°C to 750°C, the yield of char is observed as a decreased pattern and gas in an increased pattern. But the bio-oil production is observed as increased decreased pattern. The lower heat to

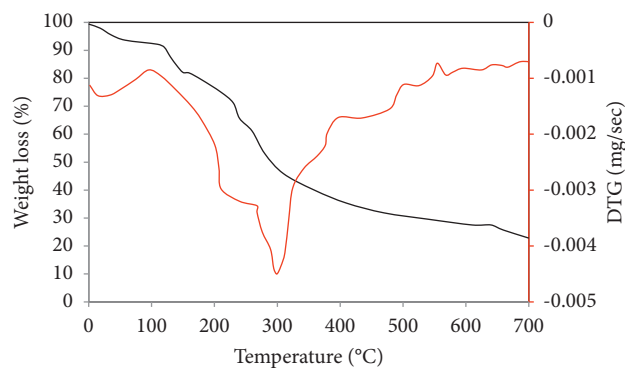


FIGURE 1: TGA and DTG analysis of *Ricinus communis* residue.

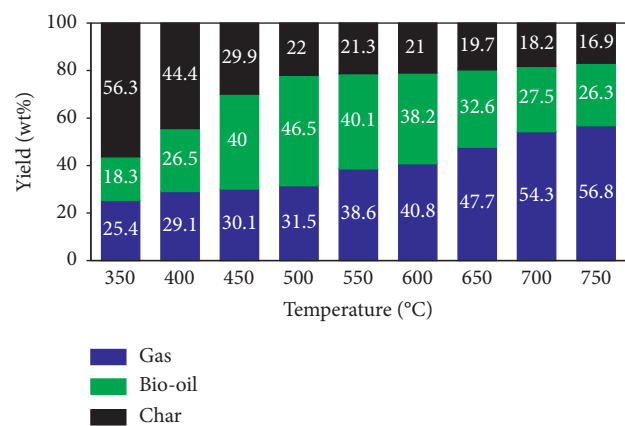


FIGURE 2: Effect of temperature on product distribution.

the material is favorable for the production of higher char. At 350°C, the char yield was 56.3 wt%, which is decreased to 16.9 at 750°C. After 500°C, there was no rapid decrease in char yield. However, after 500°C, the gas yield increased dramatically. The production of gas was increased by 80.3% at 750°C compared with 500°C. From this, it can be known that the higher temperature is favored for gas production rather than char and oil. The yield of gas at 350°C was 25.4 wt%, and it attained 56.8 wt% at 700°C. In this work, the maximum conversion of biomass into bio-oil ensued between 450°C and 550°C. In the previous literature, it is also reported that the effective pyrolysis temperatures were in the range of 470°C and 530°C [22, 23]. Table 2 shows pyrolysis of different feedstocks under different operating conditions and its outcome.

#### 3.3. Bio-Oil Characterization

**3.3.1. Physical Analysis.** The physical characteristics of pyrolysis oil vary subjected to the method of pyrolysis and quality of the feed material, and this has been documented by various authors. The pyrolysis oils contain more oxygenated elements and are denser than fossil fuels. The physical properties of the bio-oil got at 500°C are enumerated in Table 3. The bio-oil is much denser compared with neat diesel. The density is identified as 980 kg/m<sup>3</sup>. The heating value of the bio-oil is recorded as half that of fossil

TABLE 2: Pyrolysis under different operating conditions.

Feedstock	Reactor tyre	Operating condition	Quantity of the bio-oil (wt%)	Heating value of the bio-oil (MJ/kg)	Reference
Fiber board	Fixed bed	Temperature 450°C, heating rate 20 °C/min	41.9	17.14	[24]
Albizia odoratissima	Fluidized bed	Temperature 450°C, sweep gas flow rate 1.75 m <sup>3</sup> /hr	18.15	23.47	[25]
Wheat straw	Bubbling fluidized bed	Temperature 480°C	#	22	[26]
Oak wood	Auger reactor	Temperature 125°C to 175°C	47	#	[27]
Saw dust	Bubbling fluidized bed	Temperature 500°C, sweep gas flow rate 1.8 m <sup>3</sup> /hr	57.8	#	[28]
Garlic stem	Packed tube	Temperature 500°C	39.6	7.5	[29]
Pepper stem	Packed tube	Temperature 480°C	45.8	5.01	[29]
Douglas fir sawdust	Microwave	Temperature 480°C	40.25	17	[30]
Mallee wood	Fluidized bed	Temperature 300°C to 600°C, particle size 100 to 600 μm	12	22	[31]
Corn stover	Fluidized bed	Temperature 400°C, residence time 1 s	60	22.1	[32]
Lemon grass	Fluidized bed	Temperature 450°C, particle size 1 mm, sweep gas flow rate 1.75 m <sup>3</sup> /hr	50.6	19.4	[33]
Pressmud	Fixed bed	Temperature 300°C to 600°C	65	34.5	[34]
Hardwood	Vacuum	Temperature 450°C, Particle size 10 mm	16.8	16	[35]
Rice husk	Fixed bed	Temperature 400°C to 800°C, particle size 0.5 mm, sweep gas flow rate 500 to 1500 cm <sup>3</sup> /min	#	7.6	[36]
Ficus religiosa wood bark	Fluidized bed	Temperature 450°C, particle size 1.0 mm, sweep gas flow rate 2 m <sup>3</sup> /hr	47.5	18.3	[37]
Sunflower shell	Fixed bed	Temperature of 450°C, particle size 1.0 mm	46.4	#	[38]
Tea wastes	Fluidized bed	Temperature 400°C, particle size 1.0 mm, sweep flow rate 1.75 m <sup>3</sup> /hr.	46.3	21.34	[39]
Soybean cake	Circulating fluidized bed	Temperature 550°C, heating rate 5 °C/min, sweep gas flow rate 50 to 400 cm <sup>3</sup> /min	—	21.4	[40]
Neem wood bark	Fluidized bed	Temperature 450°C, particle size 1.0 mm	49.5	22.7	[41]
Napier grass	Fixed bed	Temperature 300°C to 600°C	74	40.1	[42]

#Not reported.

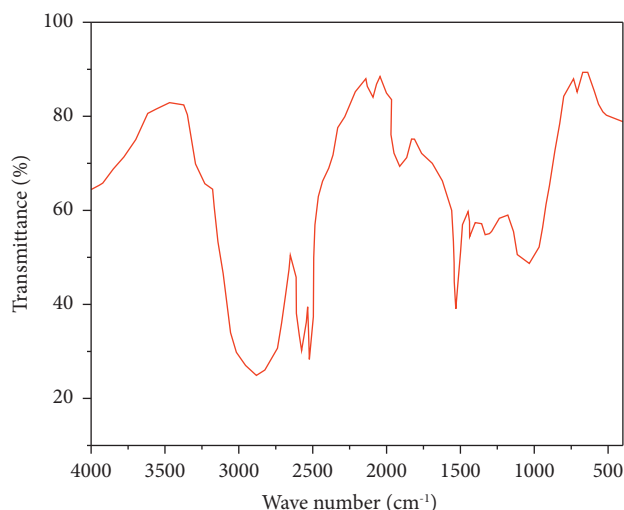
TABLE 3: Physical characterization of the bio-oil.

	Density (kg/m <sup>3</sup> )	Viscosity (cSt)	Flash point (°C)	pH	Heating value (MJ/kg)
Bio-oil [this study]	980	7.8	135	4.2	23.12
Palmyra bunch [43]	1010	8.6	160	3.9	14.5
Waste paper [44]	1205	20	200	1.5	13.10
Hard wood [45]	1220	13	66	\$	17.5
<i>Albizia amara</i> [46]	1050	4.2	160	3.6	18.6
Diesel [47]	850	3.9	57	-	43.60
Standard	ASTM D4052	ASTM D445	ASTM D92	ASTM D92	ASTM D240

§Not reported.

diesel due to higher oxygen content [48]. The heating value of the bio-oil was recorded with the help of Parr-7662 calorimetric thermometer. The pH value of was found as 4.2. Acidic chemicals are thought to be the cause of the low pH. The physical properties of the bio-oil obtained in this study were compared with other selected pyrolysis bio-oils. Compared with other bio-oils, the bio-oil obtained from *Ricinus communis* has a lower density. The lower density aid allows the fuel sprayer to flow freely. Compared with other pyrolysis oils, the bio-oil has more energy content and it is accepted to be enough for agricultural feedstock [47].

3.3.2. *FT-IR Analysis.* The existence of distinct functional groups is identified by FT-IR analysis, which is utilized to investigate the basic vibrations and related vibrational transitions [49]. In this study, major functional absorption bands were identified in the FT-IR spectrum (Figure 3). The broad band O-H stretching vibration at 2881.4 cm<sup>-1</sup> represents the existence of carboxylic acids. The C≡C stretch vibrations at 2140.2 cm<sup>-1</sup> represent the occurrence of alkynes. A broad N-O stretching appeared at 1535.8 cm<sup>-1</sup>, showing the occurrence of nitro compounds. C-O groups can be identified at 1115.6 cm<sup>-1</sup>. The peak detected at

FIGURE 3: FT-IR analysis of *Ricinus communis* bio-oil.TABLE 4: GC-MS analysis of *Ricinus communis* bio-oil.

Compound name	Retention time/min	Molecular name	Molecular weight	% area
2,5-Piperazinedione, 3-benzyl-6-isopropyl-	8.31	C <sub>14</sub> H <sub>18</sub> N <sub>2</sub> O <sub>2</sub>	246.30	3.31
Phenol, 4-ethyl-	8.53	C <sub>8</sub> H <sub>10</sub> O	122.16	4.01
Phenol	9.01	C <sub>6</sub> H <sub>6</sub> O	94.11	12.75
Phenol, 4-amino-	10.11	C <sub>6</sub> H <sub>7</sub> NO	109.12	3.75
3,4-Dimethylthiophene	11.93	C <sub>6</sub> H <sub>8</sub> S	112.19	0.94
p-Cresol	12.42	C <sub>7</sub> H <sub>8</sub> O	108.13	4.71
Di-(2-ethylhexyl) phthalate	13.11	C <sub>24</sub> H <sub>38</sub> O <sub>4</sub>	390.60	1.27
Phenol, 2-methoxy	14.44	C <sub>7</sub> H <sub>8</sub> O <sub>2</sub>	124.13	2.39
2-Methyl-5-(1-butyn-1-yl) pyridine	15.01	C <sub>10</sub> H <sub>11</sub> N	145.20	1.80
Hydroquinone	15.20	C <sub>6</sub> H <sub>6</sub> O <sub>2</sub>	110.11	9.34
Benzene, 1,3,5-trimethoxy-	15.57	C <sub>9</sub> H <sub>12</sub> O <sub>3</sub>	168.19	3.91
3-Pyridinol	18.90	C <sub>5</sub> H <sub>5</sub> NO	95.09	4.20
Phenylethyl alcohol	19.11	C <sub>8</sub> H <sub>10</sub> O	122.16	1.22
d-Mannose	20.20	C <sub>6</sub> H <sub>12</sub> O <sub>6</sub>	180.15	3.93
2,2'-Dioxospirilloxanthin	21.57	C <sub>42</sub> H <sub>56</sub> O <sub>4</sub>	624.90	1.87
2(1H)-Pyridinethione, 3-hydroxy-	22.41	C <sub>5</sub> H <sub>5</sub> NOS	127.16	0.88
2-Cyclopenten-1-one, 2,3-dimethyl-	23.50	C <sub>7</sub> H <sub>10</sub> O	122.16	1.72
1-Methyl-1,3,3-triphenylindan-2-one	23.59	C <sub>28</sub> H <sub>22</sub> O	374.10	2.28
Kaempferol	23.85	C <sub>15</sub> H <sub>10</sub> O <sub>6</sub>	286.23	1.32
2-Propenenitrile, 3-phenyl-, (E)-	24.08	C <sub>9</sub> H <sub>7</sub> N	129.15	0.74
2-Isopropyl-2,5-dihydrofuran	24.51	C <sub>7</sub> H <sub>12</sub> O	112.02	2.08
2-Acetylfuran	28.63	C <sub>6</sub> H <sub>6</sub> O <sub>2</sub>	110.11	2.40
Phenol, 2,6-dimethyl	24.87	C <sub>8</sub> H <sub>10</sub> O	122.16	3.30
Butanoic acid	25.18	C <sub>4</sub> H <sub>8</sub> O <sub>2</sub>	88.11	0.83
N-Methyldodecanamide	26.71	C <sub>13</sub> H <sub>27</sub> NO	213.36	3.47
4,5-Dimethoxy-2-(2-propenyl)phenol	27.24	C <sub>11</sub> H <sub>14</sub> O <sub>3</sub>	194.23	2.26
1,2-Benzenediol	29.36	C <sub>6</sub> H <sub>6</sub> O <sub>2</sub>	110.11	3.12
N-Benzylpiperidone	30.04	C <sub>12</sub> H <sub>15</sub> NO	189.02	1.08
Squalene	30.75	C <sub>30</sub> H <sub>50</sub>	410.71	0.33
Benzhydryl vinyl ether	31.08	C <sub>15</sub> H <sub>14</sub> O	210.21	2.31
(E)-1,2-Dibromo-1-nonene	32.34	C <sub>9</sub> H <sub>16</sub> Br <sub>2</sub>	282.34	1.94
1H-Indole, 4-methyl-	34.55	C <sub>9</sub> H <sub>9</sub> N	131.17	0.84
γ-Sitosterol	35.61	C <sub>29</sub> H <sub>50</sub> O	414.70	6.70
Asarone	37.30	C <sub>12</sub> H <sub>16</sub> O <sub>3</sub>	208.25	0.95
Cyclopentanol	38.18	C <sub>5</sub> H <sub>10</sub> O	86.13	2.02

733.6 cm<sup>-1</sup> signifies the C-H stretch that displays the presence of aromatics.

**3.3.3. GC-MS Analysis.** GC is a versatile technique used by most of the authors for the detection of thermally stable chemicals with suitable volatility. Quantification by GC has a number of advantages and is regarded as being extremely precise. Several researchers have reported using GC-MS to find various chemical components in liquid and gaseous products. Table 4 shows the analysis of GC-MS of the bio-oil. From this analysis, it can be known that phenols and their derivatives occupied the majority of the portions in the bio-oil. Phenol was identified as a single element with a total area percentage of 12.75. Next to phenol, hydroquinone is identified with a total area percentage of 9.34. The total area percentage of phenols is 28.46. The majority of the chemicals identified in bio-oil are used for numerous engineering and chemical industries. Phenol is also called carboic acid. It is an important chemical used in many engineering industries. Phenols are frequently utilized in everyday goods and as synthesis intermediates in industry. It is a good ingredient for the production of polymers, explosives like picric acid and medications like aspirin. The component of photographic developer known as common phenol hydroquinone turns exposed silver bromide crystals into black metallic silver. They are also used as a feedstock for cosmetic industries for manufacturing sunscreens, skin creams, and hair coloring agents. They were originally extracted from coal tar, but now they are produced in huge quantities from feedstocks supplied by petroleum. Due to its role as a precursor to numerous minerals and beneficial chemicals, it is a crucial industrial commodity [50]. Production of polycarbonates, bakelite, nylon, and a variety of pharmaceutical industries requires phenol and its chemical derivatives. Hydroquinone is an aromatic organic compound. It is also a type of phenol. It can be used as a reducing agent as well as in the photographic industry. The oxidation of different phenols can also be used to create hydroquinone and its derivatives. Apart from that, many of the chemicals identified in GC are combustible and identified as good hydrocarbon elements. Another chemical substance found in bio-oil is gamma sitosterol. *Achillea santolina*, *Clerodendrum infortunatum*, and other plants contain the natural gamma sitosterol.

**3.3.4. EDX Analysis.** The elements of *Ricinus communis* pyrolysis bio-oil are presented in Table 5. The outcome of this investigation made it very evident that, when compared to other elements, carbon is identified as a major one with 43.63 wt%. The presence of oxygen is almost equal to carbon with 41.37 wt%. The higher percentage of oxygen on the other side improves its combustibility during combustion. But the higher oxygen has a negative impact on its shelf life, while it is being stored. The presence of the least amount of sulfur in the bio-oil can reduce the production of sulfur oxides while burning at higher temperatures. Due to contamination in the residues, the formed pyrolysis oil comprises a minuscule quantity of chlorine. The risk of

TABLE 5: EDX analysis of bio-oil.

Element	wt%
Aluminum	1.01
Antimony	0.74
Boron	1.11
Carbon	43.63
Chlorine	0.08
Hydrogen	10.22
Iron	0.18
Magnesium	0.10
Molybdenum	0.37
Oxygen	41.37
Potassium	0.40
Silicon	0.77
Sulfur	0.05

corrosion during storage of the bio-oil can be decreased by the absence of salts. The bio-antibacterial properties and shelf life are improved by the existence of boron in the bio-oil.

#### 4. Conclusion

Pyrolysis has been shown to be a hopeful method for valuing waste biomass as a source of renewable energy. Fast pyrolysis of *Ricinus communis* residues was conducted in a fluidized bed by changing bed temperature from 350°C to 750°C. The preliminary analysis of the feedstock revealed a greater amount of volatile materials for maximum bio-oil yield. A large quantity of bio-oil production of 46.5 wt% was acquired at 500°C. A maximum conversion of biomass into bio-oil ensued between 450°C and 550°C. The analytical study of the bio-oil showed the presence of phenolic components, oxygenated chemicals, acids, and esters. The heating value of the bio-oil is recorded as half that of fossil fuel. The bio-oil produced in this study has more energy content, and it is accepted to be enough for agricultural feedstock. The chemical components identified through GC-MS are used in various engineering and chemical industries as precursors, favoring agents, and reducing agents. In summary, by being aware of the pyrolysis mechanisms, the choice of an appropriate pyrolysis method and feedstock can maximize the production of the required biofuel.

#### Abbreviations

ASTM:	American Society for Testing and Materials
CO <sub>2</sub> :	Carbon dioxide
cSt:	Centistokes
DTG:	Differential thermogravimetry
EDX:	Energy-dispersive X-ray analysis
FT-IR:	Fourier transform infrared spectroscopy
GC-MS:	Gas chromatography and mass spectroscopy
TGA:	Thermogravimetric analysis.

#### 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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