





## Research Article

# Utilization of Tea Industrial Waste for Low-Grade Energy Recovery: Optimization of Liquid Oil Production and Its Characterization

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Pyrolysis oil, produced from industrial as well as municipal solid wastes through pyrolysis, could be a viable renewable alternative fuel. In this study, abundantly available industrial tea wastes are used to produce liquid oil. Flash pyrolysis experiments on a fluidized bed reactor were performed to analyze pyrolysis characteristics. The study evaluated three important process parameters, that is, pyrolysis temperature (300–500°C), particle size (0.5–1.25 mm), and inert gas flow rate (1.5–2.25 m<sup>3</sup>/hr). The thermogravimetric analysis of the tea wastes demonstrated that the thermal pyrolysis is possible to produce pyrolysis liquid and value added chemicals. The flash pyrolysis experiment produces maximum of 46.3 wt% liquid oil at the temperature of 400°C, particle size of 1.0 mm, and the sweep flow rate of 1.75 m<sup>3</sup>/hr. The liquid products were analyzed for its physical and chemical characteristics using Fourier transform infrared spectroscopy (FTIR) and gas chromatography-mass spectroscopy (GC-MS). The heating value of the liquid products showed that it can be used as liquid fuels, and its elements can be used for various industrial applications.

## 1. Introduction

Biomass is the world's largest green energy source, accounting for 14% of global energy consumption. The expandable global population demand for energy ensures a need for continuous supply of energy in a sustainable manner. The unsustainable use of conventional fossil-based fuels escalating environmental repercussions motivates the researchers to find suitable alternative energy. As a renewable energy source, many

industrial and agricultural wastes can be utilized directly to generate heat through combustion or indirectly through conversion to various forms of biofuel. The resurgence of energy from wastes collected through industrial and agricultural processing is generally known as waste to energy concept. It depicts a lot of attention towards economic development and environmental concern [1].

The industrial wastes are broadly classified into hazardous and nonhazardous wastes. The wastes emitted from

chemical processing, mining, and radioactivity are called hazardous wastes. On the other hand, the wastes from food processing units, construction, waste paper, sugar milling, and so on are all the examples for nonhazardous wastes. According to industrial regulations, the general waste treatment methods include intermediate treatment, landfill, and reuse, according to the regulation. When opposed to land filling technique, energy from industrial wastes is noteworthy since it not only provides fuels, it saves the environment from global warming [2], greenhouse gas emissions, and land utilization as well [3]. Production of liquid fuels from huge amount of industrial and bio based wastes is gaining popularity for the past three decades due to the benefits of using these resources as feedstock [4]. Bio-chemical and thermochemical processes are the major two types of conversion techniques for energy recovery from industrial based biomass materials [5]. There are numerous studies that have reported previously biomass conversion techniques in order to improve the yield quantity [6–8]. Compared to various biomass conversion processes, pyrolysis is an effective technique to produce biofuel from low-value, biomass, and biobased industrial wastes. Pyrolysis is the most efficient method for converting biomass to a liquid intermediate that can be refined into hydrocarbon biofuels and petrochemical substitutes. It is the process of heating an organic substance in the absence of air. The type and its composition play a major role in influencing pyrolysis process and its products. Fast and flash pyrolysis is gaining more interest among the researchers to transform biomass into fuel and chemicals at low cost [9]. Among liquid gas and char, pyrolysis liquid is being the most important product since it can be stored and transported easily. It is a complex mixture of chemical substances, predominantly oxygenates [10]. The general lignocellulosic composition of biomass materials varies from one type to another, which also affects the performance of the conversion system and characteristics of the end products [11]. Biomass with higher amount of cellulose and hemicellulose produces more number of liquid products, whereas the composition of lignin components produces liquid with higher viscosity. The presence of various lignocellulosic compositions in the biomass gives complexity during pyrolysis. This complexity poses numerous challenges when it is utilized in economic way. Therefore, a thorough understanding of them is essential for creating value-added products by pyrolysis [12].

The production of tea and its consumption depends on the population of the country. India is the second top country producing 1.2 million tons of tea every year and more than 70% of the total tea consumed within the country itself. The industrial tea wastes are disposed with sewage waste, which increases the acidity of the soil and soil fertility. Tea is the most frequently consumed beverage. On a daily basis, overall up to 20 billion cups are consumed around the world, which is equal to the total consumption of coffee, chocolate, and soft drinks. In India, the majority of tea manufacturers are not following the standards issued by the tea board authorities for tea waste disposal. For each batch processing, tea industries generate a considerable amount of tea wastes including their leaves, buds, and tender. The improper disposal of these wastes

contaminates the environment, including soil, water, and air [13]. Tea industries and shops generate considerable amount of wastes, and India has a small number of tea waste purchasers. These wastes are occasionally used in the caffeine industry to extract caffeine and utilize a feed for poultry and pig. But these wastes contain a certain amount of tannic acid that limits the use for poultry and pigs feed [14]. According to Tamizselvan et al. [15], tea is grown over 5,66,660 hectares of land in India in 2020, producing up to 1250 million tones of dust per year. This huge amount of tea products generates 0.015 million tones of wastes. A minimum of 2:100 kg of tea wastes are produced during processing from the beginning to export, and the products are tested before export. The regulation board in India specified some standards in order to denature them by mixing with urea, cow manure, and other denaturants. Many researchers previously used many parts of the tea wastes for their study. Hussain et al. utilized tea leaves and transformed them as carbonaceous materials for adsorptive usage [16]. Soysa et al. used Ceylon refused tea waste for biocrude-oil production. The study compared the liquid products with Douglas fir and coffee ground oil. The study yielded oil with heating value of 15.6 MJ/kg with maximum yield of 57.2 wt% at 600°C reaction temperature. The authors suggested the produced oil to use as secondary fuel for furnace in tea industry process [17]. Recently, Tamizselvan et al. [15] utilized various parts of the tea plants for gasification to produce hydrogen rich gas products. The findings of the investigation showed that the produced gas contains considerable amounts of CO and H<sub>2</sub>, and they suggested its use as low-grade fuel for burner.

This study focused on the use of collective industrial tea wastes for liquid oil generation via thermal pyrolysis, because the combustion pathway creates a huge amount of garbage, and it creates serious environmental issues, which is not feasible for Indian context. Pyrolysis is a potential alternative approach for extracting energy and value-added chemicals. The study focused on the effect of reactor temperature, feedstock size, and nitrogen flow rate to get optimum liquid oil though flash pyrolysis experiment.

## 2. Materials and Methods

**2.1. Feedstock Collection and Preparation.** The wastes are collected from local tea manufacturers and tea industries in Udhagamandalam, India. Before utilizing the collected wastes for pyrolysis process, they need to endure two preliminary steps like milling and screening. During initial examination, the moisture content in the samples is identified as more than 10 wt%. Subsequently, the materials were dried in the sunlight for minimum one week and furnace maintained at 100°C for nearly 2 hours. After drying, the feedstocks were crushed using ball mill and screened by sieve shaker to get four different sizes of 0.5, 0.75, 1.0, and 1.25 mm. Generally, the feedstock with minimum diameter is advised for thermochemical conversion processes in order to overcome the heat transfer restriction during process [18].

**2.2. Characterization Study.** The initial characterization study of tea wastes to find the suitability for pyrolysis process

was performed by proximate and ultimate analysis. The elemental analysis for the sample and liquid products was analyzed by Elementar Vario EL-III series. The heating value of the sample as well as liquid was measured using a bomb calorimeter (Parr-6772). The effect of applied heat on mass fraction of the material during pyrolysis process was investigated using TGA701 thermogravimetric analyzer heated at 10°C/min under N<sub>2</sub> environment.

**2.3. Pyrolysis Setup and Procedure.** A series of pyrolysis experiments were performed in a lab-scale fluidized bed reactor consisting a reactor, biomass feeding system, sweep gas flow system, temperature control system, condenser with cooling circuit, and char separation system. Normal sand with average diameter of 0.5 mm is used within the reactor for fluidization purposes. The reactor is fully insulated with mineral wool and Chromel–Alumel to resist unnecessary heat loss from the reactor. The reactor is in cylindrical shape of 150 mm long and 50 mm diameter. The cyclone separators are attached with the outlet of the reactor to collect escaped char and dust from the reactor. The feedstock supplied to the reactor is allowed through screw feeder and hopper arrangement connected with a variable speed motor. The biomass particles were retained in the hopper and fed into the reactor with specific flow rate. A small rotameter is attached with nitrogen flow unit to measure and control the flow rate. The temperature of the reactor is measured using five K type thermocouple located at five different points inside the reactor, and the heat input is controlled by the autotransformer. After heating the sand particles to fixed temperature, the air was cut off, and N<sub>2</sub> was delivered. The velocity of the gas is maintained two times greater than minimum fluidization velocity of 0.11 m/s. The minimum fluidization velocity for this study is measured using a 1m long glass tube with a diameter of 50 mm [19]. For this analysis, 500 g of sand particles is used. Air was employed as the fluidizing gas, and its flow rate was monitored with a rotameter. The decrement of pressure in the glass column was measured with a Mercury manometer. The position of the bed material did not change when air was entered at first, and the pressure drop increases with increased flow rate and reaching a maximum value at the point of initial fluidization. Increment in velocity over that limit does not result in an increase in bed pressure drop, but the elements reorganize themselves to allow more space around them to accommodate further gas flow. Finally, the velocity is found by using formula  $Q = AV$ . The pyrolyzed gas was condensed for liquefaction using a condenser unit maintained with adequate cooling water.

The collected and screened tea wastes were successfully transformed into pyrolysis oil, noncondensable gas, and char by optimizing process parameters. The experimental aim is to collect large quantity of pyrolysis liquid. For this, the biomass material is fed into the reactor and is heated to the desired temperature. The evolved gases were then transferred through a condenser. The condensable volatiles are successfully converted into liquid and collected with the aid of water-cooling condensers. In order to get maximum

condensation, the condensed water is maintained at 0°C. The liquid products are measured directly in order to find the effective conversion rate. The char products are collected directly and weighed using weighing balance machine. The yield of noncondensable gases is calculated by simple material balance method. For the production of quantitative liquids, several experimental parameters, such as pyrolysis temperature (300 to 500°C), particle size (0.5 to 1.25 mm), and fluidizing gas flow rate (1.5 to 2.25 m<sup>3</sup>/hr), were optimized. Table 1 represents the experimental condition in each stage.

**2.4. Liquid Phase Analysis.** The collected samples obtained at optimized experimental conditions were preserved and tested for their physical and chemical characteristics. FTIR and GC-MS were used to determine the organic and inorganic composition of pyrolysis liquid. The functional group present in the liquid was analyzed by BRUKER TENSOR 27 FTIR spectrometer. The FTIR spectra were collected in the range of 400–4000 cm<sup>-1</sup> with 4 cm<sup>-1</sup> resolution. The GC-MS analysis was performed using Thermo Scientific GC of capillary column (length: 30 m, diameter: 0.25 mm, film thickness: 0.25 μm), and a DSQ-II MS was utilized. The analysis is performed to acquire a better understanding of the aging process and the compositional changes in the liquid products. Table 2 illustrates the program utilized for GC-MS analysis. NIST MS library identifies the chromatographic peaks listed based on their retention time. The peak percentages were identified using total ion chromatogram peak area.

### 3. Results and Discussion

**3.1. Feedstock Characterization.** Tables 3 and 4 portray proximate and ultimate analysis of the tea wastes. The analysis was done by following ASTM standards. The data showed higher percentage of volatile contents of 70.42 wt%, 19.52 wt% fixed carbon, 6.31 wt% moisture content, 3.75 wt% ash content with 46.3 wt% carbon, 6.1 wt% hydrogen, 3.7 wt% nitrogen, and 1.1 wt% sulphur. The presence of higher volatile matter in the tea wastes can yield maximum liquid products during pyrolysis reaction [20]. The nitrogen and sulphur contents were quite low, making it more environmentally-friendly when burning in the furnace. In addition to that, it has lower amount of moisture and medium level of ash content. The higher heating value of the material was recorded as 18.2 MJ/kg. The low heating value is primarily due to the high oxygen level of the sample.

**3.2. Thermal Analysis.** Figures 1 and 2 show TGA and DTG results obtained under inert atmosphere. The analysis is done from atmospheric temperature to 600°C. The initial mass fraction started at 75°C and reached maximum after 200°C. In between 250°C and 450°C, the maximum mass loss appeared. The volatiles present in the tea wastes were released more at this temperature range. The major source of the maximum mass loss at this range is due to higher degradation with high cellulose and hemicellulose content.

TABLE 1: Experimental condition.

| Experimental aim                                   | Ranges                     | Fixed parameters   |
|--|----------------------------|--|
| Optimizing pyrolysis temperature (°C)              | 300, 350, 400, 450 and 500 | Particle size: 0.75 mm<br>N <sub>2</sub> flow rate: 1.5 m <sup>3</sup> /hr |
| Optimizing particle size (mm)                      | 0.5, 0.75, 1.0 and 1.25    | Temperature: 400°C<br>N <sub>2</sub> flow rate: 1.5 m <sup>3</sup> /hr     |
| Optimizing sweep gas flow rate (m <sup>3</sup> /h) | 1.5, 1.75, 2.0 and 2.25    | Temperature: 400°C<br>Particle size: 1.0 mm                                |

TABLE 2: GC-MS condition.

| Instrumentation       | Set parameter |
|-----------------------|---------------|
| GC conditions         |               |
| Column temperature    | 70°C          |
| Injection type        | Split         |
| Injection temperature | 200°C         |
| Split ratio           | 10            |
| Carrier gas           | Helium        |
| Column length         | 30 m          |
| Diameter              | 0.25 mm       |
| Film thickness        | 0.25 μm       |
| MS conditions         |               |
| Source temperature    | 200°C         |
| Interface temperature | 250°C         |
| Range                 | 50–650 m/z    |

TABLE 3: Proximate analysis in wt%.

| Volatile matter | Fixed carbon | Moisture content | Ash content |
|-----------------|--------------|------------------|-------------|
| 70.42           | 19.52        | 6.31             | 3.75        |

TABLE 4: Ultimate analysis (ash free basis) in wt%.

| Carbon | Hydrogen | Nitrogen | Sulphur | Oxygen <sup>a</sup> |
|--------|----------|----------|---------|---------------------|
| 46.3   | 6.1      | 3.7      | 1.1     | 42.8                |

<sup>a</sup>By difference.

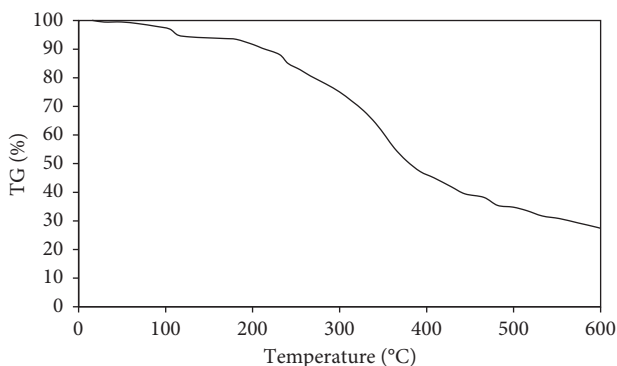


FIGURE 1: Thermogravimetric curve.

After reaching 500°C, no mass loss appeared. Cellulose, hemicellulose, and lignin are the common basic elements of all biomass material. The breakdown of these components has a significant impact on the yields of pyrolysis products. Previously, many researches have shown that hemicellulose begins to breakdown around 150–350°C, whereas cellulose

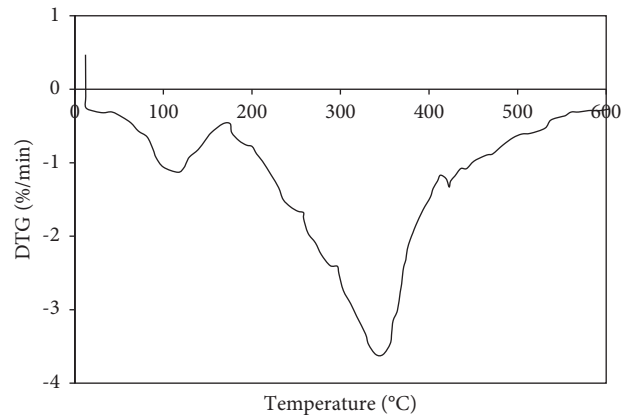


FIGURE 2: Derivative thermogravimetric curve.

degradation takes place between 275 and 350°C. However, breakdown of lignin occurs from 200 to 600°C [21]. According to these findings, the majority of weight loss occurs due to hydrocarbon volatilization at temperatures lower than 600°C. Hence, setting reaction temperature from 300 to 500°C is appropriate to produce liquid products [22].

### 3.3. Pyrolysis Yields

**3.3.1. Influence of Temperature.** The influence of reactor temperature on product distributions of industrial tea wastes is shown in Figure 3. As shown in the figure, the fraction of liquid products increases from 32.2 wt% to 39.2 wt% as the temperature rises from 300 to 400°C. The liquid yield is then decreased to 33.5 wt% as with the increase of temperature to 500°C. The reason behind the increased and decreased pattern of liquid yield is the multiple types of reactions in the reactor. The primary and secondary reactions inside the reactor are producing condensable vapors and gaseous products, which are then condensed to generate pyrolysis liquid [23]. The secondary reactions of the char particles produce more amount of noncondensable molecules and aid in increasing gas products. Generally, primary reactions reign at lower temperatures, and as reaction temperatures increases, the formation of vapor gets increased, resulting in increased vapor condensation and high liquid yield. However, further increase in temperature gives the way for secondary reactions, leading to more gaseous products [24]. When the temperature is increased above 400°C, the yield of char decreased, and the higher temperature boosts the conversion of carbon into gaseous products. Hence, the yield

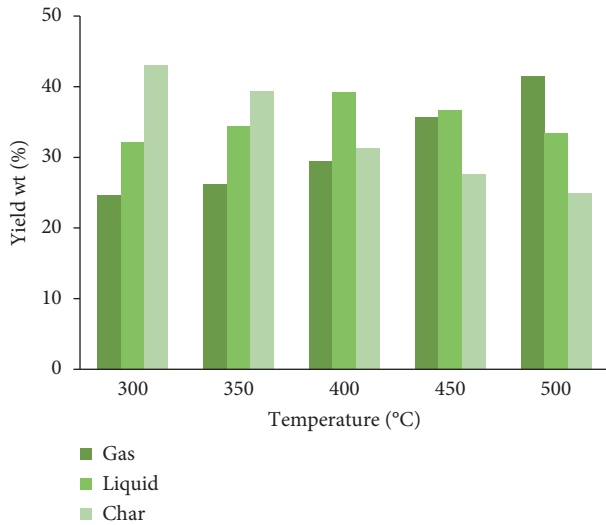


FIGURE 3: Effect of temperature on pyrolysis product yield.

of gas is increased steadily from 24.7 wt% at 300°C to 41.5 wt% at 500°C. The yield of char is continuously decreased from 43.1 to 25.0 wt% for the temperature raises from 300 to 500°C. The increased char products at lower temperature are due to the lower decomposition of the feed particles at poor temperature, and further increase in temperature enhances the heat transfer from the outer to the center core and creates higher fraction of volatiles. A similar pattern was seen in the literature with various biomass samples [25, 26].

**3.3.2. Influence of Particle Size.** The size of the particles is an important one to consider for pyrolysis process since it influences the rate at which heat is transmitted to the center core of the biomass. The increased particle sizes slow down the heat passage from the hot to the cold end, which favors the yield of char [27]. Also, higher particle diameter is triggering secondary reactions and promotes them to yield more char. Figure 4 illustrates the effect of tea waste particle size on product yield. In this case, the yield of liquid products is enhanced from 37.6 wt% to 43.1 wt% as the particle size of biomass increases from 0.5 mm to 1.0 mm. The increment in particle size after 1.0 mm reduces the yield to 41.2 wt%. The change of biomass diameter from 0.5 mm to 1.25 mm did not much affect the production of char and gas. The production of char and gaseous products is changed from 32.5 wt% and 29.9 wt% to 30.1 wt% and 28.7 wt% when the decrement in the particle size is found from 0.5 mm to 1.25 mm. Only 7.38% and 4% differences were found for char and gas yield between these selected particle sizes. This is similar to previous investigations [28–30], which found that if the particle size was small enough, the particle could be heated uniformly. This study revealed that mass- and heat-transfer constraints had a significant impact on oil yield at large particle sizes exceeding 1.0 mm, resulting in lower liquid yield.

**3.3.3. Influence of  $N_2$  Flow Rate.** Another component that has an impact on the yield is the flow of carrier gas or sweep

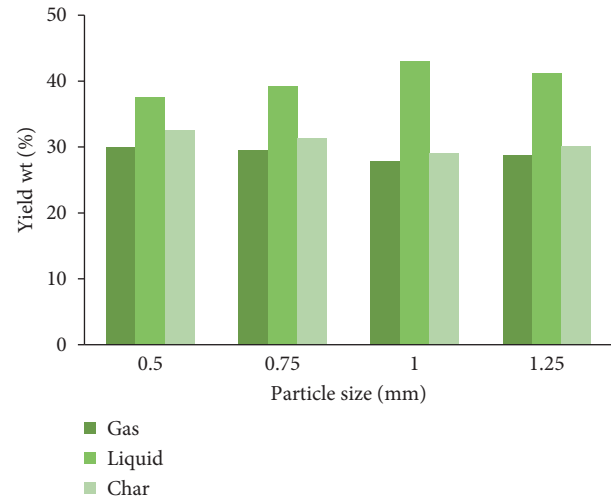


FIGURE 4: Effect of particle size on pyrolysis product yield.

gas. During fluidized bed pyrolysis, a moderate to high amount of vapors are produced, and if they are not expelled, they might become involved in the secondary processes and alter the total composition [31]. Nitrogen, helium, and argon are the commonly used gases for sweeping purpose, out of which nitrogen is used for this study since it is nontoxic, less expensive than the others, and widely available. The improper flow rate not only affects the residence time, but also reduces the secondary breakdown of higher molecular weight products in the hot region. There are a large number of studies focusing on the yield trend by changing its sweep gas flow rate [32, 33]. The influence of  $N_2$  flow rates on the yield of the products is depicted in Figure 5. The study shows higher liquid yield of 46.3 wt% at 1.75 m<sup>3</sup>/h. However, it was shown that when the  $N_2$  flow rate exceeded 1.75 m<sup>3</sup>/hr, the production of the liquid fractions reduced significantly, which is related to the material fluidization characteristics, residence time, and the heat flow rate within the particle. In proportion to the increase in  $N_2$  flow rate, the material inside the reactor becomes more vigorous and enhances heat transfer rate between fluidized medium and biomass. On the other side, there is reduction in residence time reducing the probability of tar cracking.

### 3.4. Characterization of the Liquid Products

**3.4.1. Physical Characterization.** Table 5 shows the elemental compositions and some of the basic properties of the liquid products obtained under optimized conditions. The liquid is found as denser than diesel fuel. The viscosity and flash point are recorded as 4.1 cSt and 135, respectively. Higher viscosity and density are closely related to the performance of the atomizer when it is used as the fuel for fire. The HHV is found as 21.34 MJ/kg, which is much better for pyrolysis oil produced from biomass materials. The property of the liquid obtained in this study is similar as the pyrolysis oil obtained from different biomass materials [34, 35].

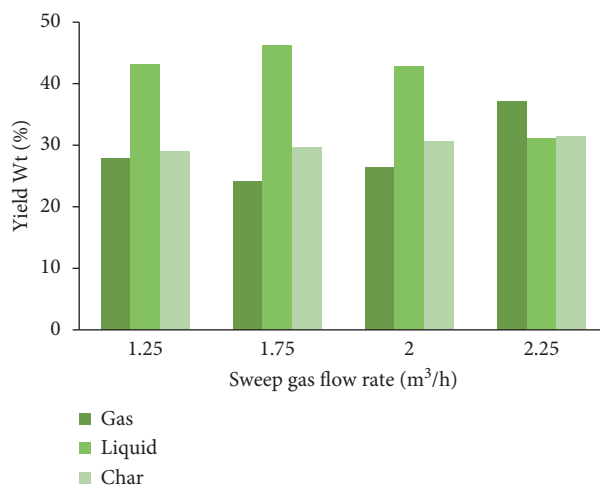


FIGURE 5: Effect of N<sub>2</sub> flow rate on pyrolysis product yield.

TABLE 5: Properties of the liquid.

| Component                    | Value |
|------------------------------|-------|
| Density (kg/m <sup>3</sup> ) | 980   |
| Viscosity (cSt)              | 4.1   |
| Flash point (°C)             | 135   |
| pH value                     | 4.8   |
| Carbon (wt%)                 | 51.33 |
| Hydrogen (wt%)               | 7.63  |
| Nitrogen (wt%)               | 5.14  |
| Sulphur (wt%)                | 0.02  |
| Oxygen <sup>a</sup> (wt%)    | 35.88 |
| H/C                          | 1.771 |
| O/C                          | 0.524 |
| HHV (MJ/kg)                  | 21.34 |

<sup>a</sup>By difference, C,H,N,S-ash free basis.

**3.4.2. FTIR Spectra Analysis.** A large variety of complex organic compounds can be found in the oils. Figure 6 depicts the FTIR spectra of the entire liquid fractions. The identified phenols and alcohols are in the sample indicated by the presence of O–H stretching vibrations between 3000 and 3350 cm<sup>-1</sup>. The existence of alkanes can be determined by the presence of C–H stretching vibrations in the spectra between 2750 and 2950 cm<sup>-1</sup> and C–H deformation vibrations between 1300 and 1450 cm<sup>-1</sup>. Furthermore, the bending vibration of C–H groups is located at 1287 cm<sup>-1</sup> providing the existence of methyl groups in the sample. Carbonyl stretching absorptions are responsible for the presence of the band at approximately 1746 cm<sup>-1</sup> in the spectra. The identification of C–O stretch at 1124 cm<sup>-1</sup> and 1010 cm<sup>-1</sup> indicates the presence of alcohols.

**3.4.3. GC-MS Analysis.** GC-MS spectroscopy was performed on the liquid sample that was obtained under optimal conditions. A total of 25 major compounds were acknowledged including phenols, alkenes, acids, furans, ketones, nitride, alcohols, and esters. In particular, D-glucopyranoside-D-glucopyranosyl, acetic acid, phenol, 2,6-dimethoxy, nonacosane, and some amounts of caffeine were

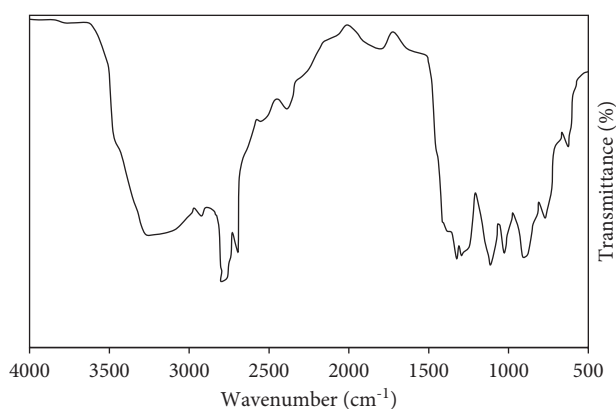


FIGURE 6: FTIR spectra of the liquid.

identified. The area percentages of D-glucopyranoside-D-glucopyranosyl, acetic acid, phenol, 2,6-dimethoxy, nonacosane, and caffeine are 14.22, 10.45, 7.97, 6.01, and 5.31, respectively. There were a number of additional substances identified in lower levels including 2-methoxy-4-methylphenol, 2-methyl-furan, phenol, 4-propyl, 2-phenyl-1-p-tolyethanol, ricinoleic acid, and phenol. The total number of components identified in GC-MS is listed in Table 6.

**3.5. Industrial Applications of the Oil Product.** The practical applicability of pyrolysis oils as a renewable fuel is still limited, but it is gaining more interests nowadays. The raw pyrolysis oils cannot be blended easily with conventional petroleum-based synthetic fuels [36]. However, the compounds extracted from this pyrolysis liquid can be broadly used in a variety of industries such as pharmaceutical, health care, and cosmetic. Phenols and their derivatives found in the oil are widely used in food, transportation, and coloring agents [37]. The presence of carbonyl compounds and acetic acid can be refined into natural antibacterial agents [38]. The fatty acid contents also can be used in the production of natural pesticide. The study suggests that the liquid products produced using industrial tea wastes eventually take the role

TABLE 6: GC-MS analysis of tea waste pyrolysis oil.

| Rt (min) | Name of the compound                        | Molecular formula  | Area % |
|----------|---|--|--------|
| 1.01     | 2-Methoxy-4-methylphenol                    | C <sub>8</sub> H <sub>10</sub> O <sub>2</sub>                | 1.90   |
| 1.21     | 2-Methyl- furan                             | C <sub>5</sub> H <sub>6</sub> O                              | 2.62   |
| 1.56     | Benzene                                     | C <sub>6</sub> H <sub>6</sub>                                | 0.92   |
| 2.09     | Ethyl-piperidine                            | C <sub>7</sub> H <sub>15</sub> N                             | 1.09   |
| 3.12     | Methyl-pyridone                             | C <sub>6</sub> H <sub>7</sub> N                              | 0.46   |
| 3.55     | Phenol, 4-propyl-                           | C <sub>9</sub> H <sub>12</sub> O                             | 5.44   |
| 4.01     | Tridecylene                                 | C <sub>13</sub> H <sub>28</sub>                              | 5.51   |
| 6.41     | Acetic acid                                 | C <sub>2</sub> H <sub>4</sub> O <sub>2</sub>                 | 10.45  |
| 7.65     | Eicosane                                    | C <sub>20</sub> H <sub>42</sub>                              | 2.44   |
| 7.92     | Octadecenoic acid                           | C <sub>18</sub> H <sub>36</sub> O <sub>2</sub>               | 5.02   |
| 10.46    | Hexanedioic acid, bis(2-methylpropyl) ester | C <sub>14</sub> H <sub>26</sub> O <sub>4</sub>               | 4.73   |
| 12.20    | Nonacosane                                  | C <sub>29</sub> H <sub>60</sub>                              | 6.01   |
| 15.46    | D-glucopyranoside,D-glucopyranosyl          | C <sub>6</sub> H <sub>12</sub> O <sub>6</sub>                | 14.22  |
| 15.92    | Phenol, 2,6-dimethoxy                       | C <sub>8</sub> H <sub>10</sub> O <sub>3</sub>                | 7.97   |
| 16.05    | 2-Phenyl-1-p-tolyethanol                    | C <sub>14</sub> H <sub>16</sub> O                            | 3.90   |
| 16.67    | Phenol                                      | C <sub>6</sub> H <sub>6</sub> O                              | 2.41   |
| 16.99    | 3-Methyl phenol                             | C <sub>7</sub> H <sub>8</sub> O                              | 3.09   |
| 20.18    | Tetradecane                                 | C <sub>14</sub> H <sub>30</sub>                              | 0.70   |
| 21.41    | Ricinoleic acid                             | C <sub>18</sub> H <sub>34</sub> O <sub>3</sub>               | 5.41   |
| 22.83    | Caffeine                                    | C <sub>8</sub> H <sub>10</sub> N <sub>4</sub> O <sub>2</sub> | 5.31   |
| 24.67    | Pyridine 2-methyl                           | C <sub>6</sub> H <sub>7</sub> N                              | 0.63   |
| 25.72    | 4-Methyl-5h-furan-2-one                     | C <sub>5</sub> H <sub>6</sub> O <sub>2</sub>                 | 0.24   |
| 29.33    | 2,20-Dioxospirilloxanthin                   | C <sub>42</sub> H <sub>56</sub> O <sub>4</sub>               | 3.66   |
| 31.41    | 4-Ethyl-2-methoxy phenol                    | C <sub>9</sub> H <sub>12</sub> O <sub>2</sub>                | 1.40   |
| 33.69    | 1,2-Bis(20-quinolymethyl)ethylene           | C <sub>20</sub> H <sub>14</sub> N <sub>2</sub>               | 3.20   |

of fossil asphalt due to its considerable heating value. The compounds extracted from pyrolysis oils show promise as environmental remediation agents.

#### 4. Conclusion

The tea wastes obtained from industrial processes were collected and subjected to pyrolysis process with the aim of avoiding the disposal with sewage and utilizing it for energy recovery. The pyrolysis studies show higher liquid output of 46.3 wt% by keeping reactor temperature of 400°C, 1.0 mm particle size, and at N<sub>2</sub> flow rate of 1.75 m<sup>3</sup>/hr. The results are explicitly that the yield of liquid is the function of pyrolysis temperature. In this study, temperature is the important factor that determine the yield rather than particle size and inert gas flow rate. Thus, a good platform is made thorough this study for the utilization of industrial tea wastes to produce burner oil with heating value of 21.34 MJ/kg. According to GC-MS investigation, the liquid product consists with a mixture of variety of oxygenated aromatics. The presence of phenols, carbonyl compounds, acetic acid, and fatty acid components can be used for pharmaceutical, health care, cosmetic, food, and transportation industries.

#### Abbreviations

FTIR: Fourier transform infrared spectroscopy  
 GC-MS: Gas chromatography-mass spectroscopy  
 CO: Carbon monoxide  
 H<sub>2</sub>: Hydrogen  
 Q: Flow rate of the air (m<sup>3</sup>/h)  
 A: Area of the fluidization column (m<sup>2</sup>)

V: Velocity (m/s)  
 ASTM: American society for testing and materials  
 TGA: Thermogravimetric analysis  
 DTG: Derivative thermogravimetric  
 HHV: Higher heating value in (MJ/kg).

#### 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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