

Effect of Pyrolysis Temperature and Biomass Composition on Bio-Oil Characteristics

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ABSTRACT

Pyrolysis is a method of producing oils from the raw materials of biomass by decomposing the thermochemical of organic materials at a given temperature. Free variables used in this research include pyrolysis temperature and biomass composition. The temperature variation of pyrolysis consists of three ranges: 100–200; 200–300; and 300–350 °C. Meanwhile, the composition of biomass consists of five combinations of waste rubber and coconut shells ranging from 0% coconut shell and 100% rubber wood to 80% coconut shell and 20% rubber shell. The physical characteristics of bio-oil analyzed include volume, pH, density, viscosity, and GC-MS analysis to determine its chemical characteristics. Research results showed that the pyrolysis temperature and composition of the biomass affected the characteristics of the bio-oil. The results of GC-MS analysis on bio-oil at 300–350 °C showed that bio-oil with a biomass composition of 80% coconut shells and 20% rubber wood yielded 50.19% phenol. The percentage of phenol is greater than that found in bio-oil with 20% coconut shells and 80% rubber wood, which is 18.78% phenol.

Keywords: biomass, waste to energy, rubber wood waste, coconut shell waste, electric pyrolysis, spectrometry analysis, gas chromatography mass.

INTRODUCTION

Indonesia has a high intensity of sunlight and precipitation, thus impacting good soil fertility. This fact made Indonesia one of the agricultural countries. Indonesia can be the largest source of energy for biomass because it has high agricultural and plantation sectors, as well as abundant natural resources. The basic needs of life in Indonesia such as foods and cloth are increasing as Indonesia's current population grows. One of the problems caused by the increasing amount of waste that is not being used anymore, such as biomass waste. Biomass waste is an organic material that can easily found around us, such as rubber wood waste and coconut shell waste. Most of these waste have not yet been utilized to increase the value of use. The use of biomass as alternative energy to address the energy crisis has

been made in the government's plan. The national energy supply target for the development of new and renewable energy by 2025 is 23%. Until now, the use of rubber wood as a biomass is still limited compared to the available amount. Although of hardwood type, the quality of rubber wood is low as a building material, so it is only used as a conventional fuel and causes pollution. South Sumatera has the largest area of rubber plantations and as one of the largest rubber producer in Indonesia. The average rubber plantation area in South Sumatera is 868,679 ha with a total production of 873,309 Ton in the last 3 years.

Coconut shell waste comes mostly from the coconut fruit processing industry, traditional markets, and household activities. The location of the coconut shell is on the inside of the coconut after the coir. Coconut shell is a hard layer with a thickness of 3–5 mm, so it belongs to the hardwood

group [Rusydi, 2019]. Coconut shells have 15–10% weight of the total weight of the coconut fruit. According to data from the South Sumatera Central Statistical Agency [2020] the production of coconut plantation plants in South Sumatera in 2020 reached 57,570 tons. From 58.3 kg of coconut produced 33% of coconut shells were waste or equivalent to 19.3 kg [Harsono, 2018].

Bio-oil has the characteristics of a black liquid that is combustible, highly acidic, corrosive, high viscosity, and contains quite high water content. The characteristics and composition of bio-oil depend on the composition of raw materials and other process parameters such as particle size, temperature, reaction time, heating speed, and particle size of biomass [Novita et al., 2021]. With its high level of volatility, bio-oil has the potential to produce good quality product. Bio-oil is composed of various condensed organic vapor such as acids, alcohols, esters, ethers, furan, acetaldehyde, aldehyde, ketone, methanol, and other hydrocarbons [Jacobson et al., 2013]. The composition of bio-oil is influenced by several factors such as the type of biomass, water content, and the temperature of pyrolysis processes. The largest organic components in bio-oil are lignin derivatives such as phenol, aldehyde, ketone, acid, ester, amine, ether, and nitrogen [Gracia-Vitoria et al., 2023].

Phenol is an important raw material in several industries such as production of phenol resins, plastics, pesticides, ink, and fuel additives. So far phenols are generally produced from petroleum, so their price and availability are dependent on petroleum [Sangthong et al., 2022]. Biomass containing lignocellulose and lignin can be an alternative source of phenols and their derivatives. Compared to petroleum-derived phenols, the pyrolysis phenols of biomass are more environmentally friendly and readily available. Phenol from bio-oil not only can be used as a raw material replacement on phenol resins production, but it can also be used as a raw material in developing bio-based antioxidants and other uses [Shah et al., 2017]. This study is intended to determine the effect of pyrolysis temperature and the composition of raw materials used, namely rubber wood and coconut shells on the characteristics of the bio-oil produced. Therefore, this study requires a pyrolysis device that controls temperature so that electric furnace is needed as a heat source. To determine the content of compounds in bio-oil and the effect of raw material composition on phenol percentage

in bio-oil, a gas chromatography mass spectrometry (GC-MS) analysis is performed.

EXPERIMENTAL SECTION

The following diagram showed the overall process to produces bio-oil starting from literature study to designing and manufacturing of pyrolysis device. The raw material that used in this research consists of various combinations. Some analysis to determine bio-oil's physical characteristics are going to be conducted, such as pH, density, and viscosity. Meanwhile GC-MS analysis will be used to detect the content of chemical compounds in bio-oil (Figure 1).

Materials

Rubber wood waste was obtained from local plantation on Inderalaya, Sumatera Selatan, Indonesia. While the coconut shell waste were Acquired from traditional market around Palembang, Sumatera Selatan, Indonesia. Electric pyrolysis device instruments or equipments were purchased from various Indonesia's market places.

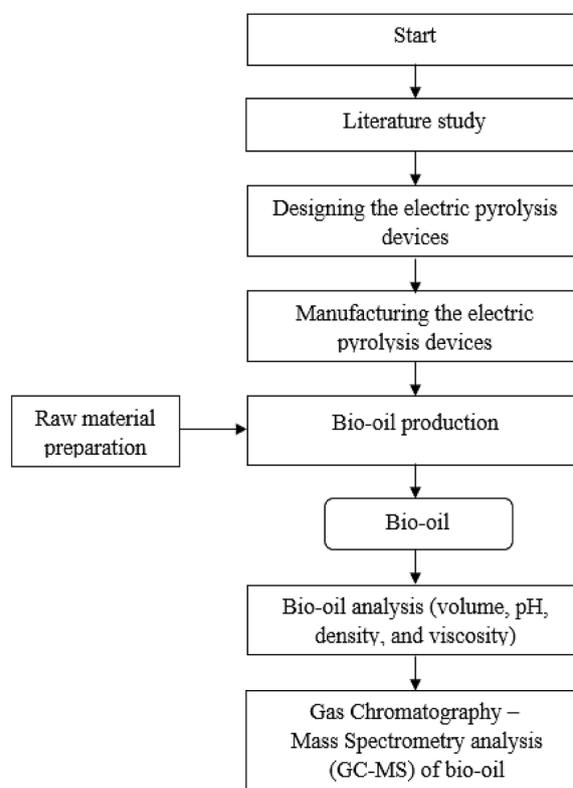


Figure 1. Block diagram of bio-oil production processes

Instrumentation

The instruments used in this research is self-manufactured electric pyrolysis device. The pyrolysis reactor is designed to fulfill the free variable of pyrolysis temperature with a capacity of 5 kg raw material. The pyrolysis device consists of reactor, electric furnace, condenser, and piping system to obtain bio-oil. The electric pyrolysis device and it's temperature control system are illustrated in the Figure 2.

Procedure

After designing and manufacturing electric pyrolysis device, the production process of bio-oil is carried out with some steps.

Pre-treatment of raw material

The raw material pre-treatment with oven at 105 °C for 60 minutes is aimed to remove water content in the biomass. The pre-treatment process is showed below (Figure 3). After the raw material is dried, it will proceed to sample preparation according to the desired composition. There are five samples with different compositions of raw materials on a 5 kg basis as shown in Table 1.

Bio-oil analysis

Measurements and analysis of pyrolysis products include volume, pH, density, viscosity, and gas chromatography – mass spectrometry (GC-MS).

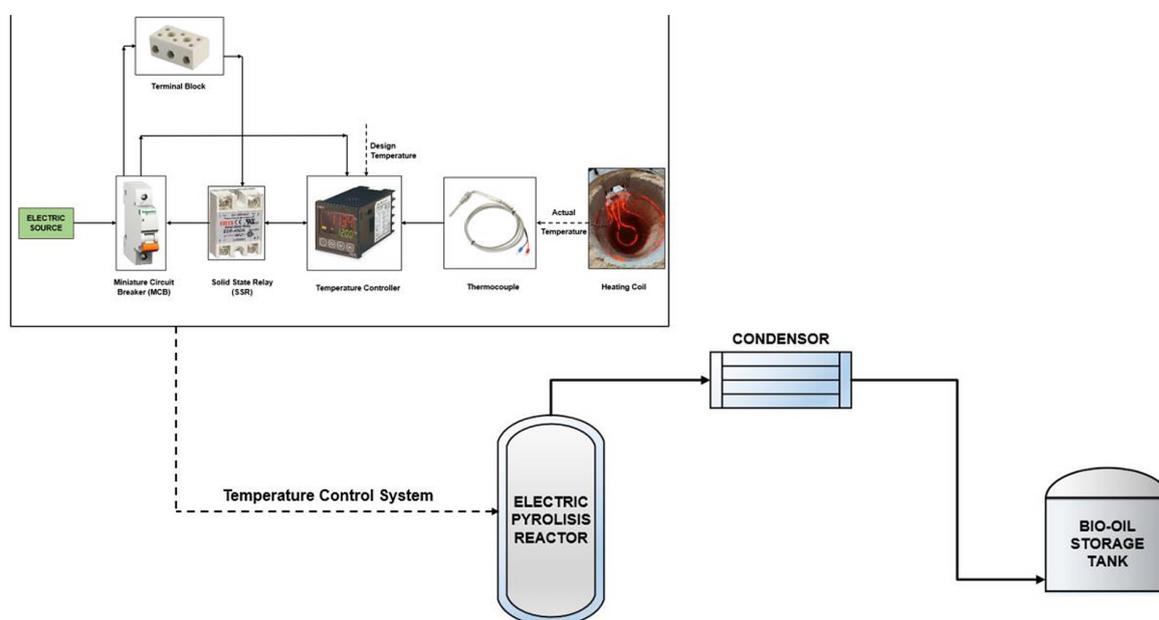


Figure 2. Illustration of electric pyrolysis device with temperature control system procedure



Figure 3. The pre-treatment of raw material

Table 1. Raw material compositions

No	Sample	Raw material compositions (%)	
		Rubber wood	Coconut shell
1.	A	100	0
2.	B	80	20
3.	C	60	40
4.	D	40	60
5.	E	20	80

pH

The degree of acidity or pH of the bio-oil is measured using a digital pH meter that was first calibrated.

Density

The density of bio-oil is measured using a pycnometer by applying the formula (Eq. 1):

$$\text{Density} = \frac{m_2 - m_1}{V} \quad (1)$$

where: m_1 – empty pycnometer mass (gram), m_2 – pycnometer mass with content (gram), V – capacity of pycnometer (mL)

Viscosity

The viscosity is measured using the Ostwald viscometer with a factor $c = 0.09713$. So the formula used is (Eq. 2):

$$\text{Viscosity} = t \times c \quad (2)$$

where: t – time (s), $c = 0.09713$

Gas chromatography – mass spectrometry

GC-MS analysis is required to determine the content of chemical compounds in bio-oil. This analysis was carried out in the laboratory of the Faculty of Chemistry in Sriwijaya University.

RESULTS

The study was conducted on three temperature ranges of 100–200; 200–300; and 300–350 °C. The temperature is chosen according to the decomposition process of the compound in the raw material, where at 200–250 °C there is a decomposition of hemicellulose, and a decomposition of cellulose at 280–320 °C [Diatmika, 2019]. Lignin has a wider decomposition temperature range of 200–700 °C [Suyitno et al., 2009]. The pyrolysis process runs continuously for all three temperature ranges until the raw material is decomposed, which is characterized by condensers that no longer emit bio-oil and residual gas. The characteristics of bio-oil such as pH, density, and viscosity are important parameters to be analyzed as they affect their use performance.

The influence of the three temperature ranges affects the bio-oil volume resulting from the five composition variations yielding the lowest value of 45 mL at 100–200 °C pyrolysis and the largest value of 1327 mL at 300–350 °C. Figure 4 shows a graph of the influence of composition and pyrolysis temperature on the volume of bio-oil produced. Results from the graph show that there is an increase in bio-oil volume resulting from pyrolysis at 100–200 °C and tends to decrease from 200 °C to above 300 °C.

The pyrolysis process begins and the raw material has begun to decompose at 200 °C, resulting in an increase in the volume of bio-oil. In samples D and E the pyrolysis apparatus takes 44 minutes to reach 300 °C from 200 °C, thus obtaining a higher volume of bio-oil. For samples A, B, and C, it takes only 34 minutes. This is because during the running of samples A, B, and C the efficiency of the instrument is

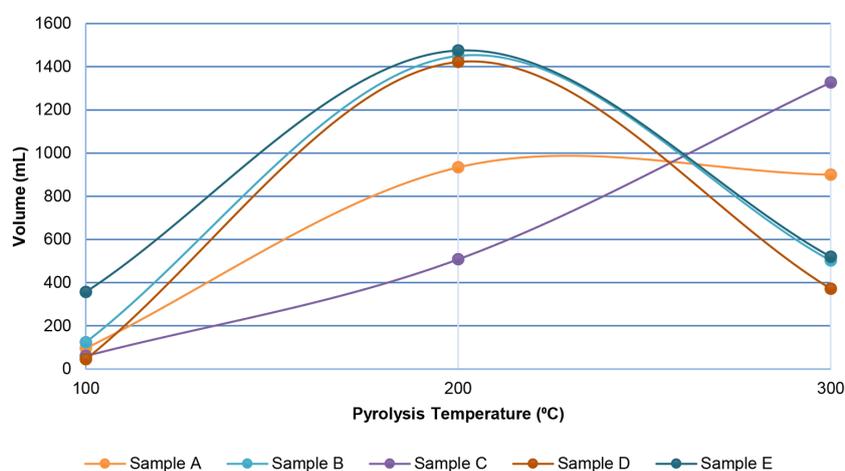


Figure 4. Bio-oil volume at various pyrolysis temperatures and raw material compositions

still high. Whereas for D and E samples, the efficiency of the device has decreased, such as thinning the gasket and deterioration of the hex nut on the cover of the device, then the time it takes to reach 300 °C is longer.

At temperatures above 300°C, the raw materials begin to decompose and the volume of bio-oil obtained is decreased. High bio-oil volume exists in samples with more coconut shell composition than rubber wood. Rubber wood contains 12.51% water content [Darmadji et al., 2000]. Meanwhile, coconut shell composition contains 8% water content (Rizal et al., 2020) So the more water content, the less volume, the more time it takes to produce bio-oil.

The study conducted by Orhevba et al. [2013] stated that the higher the moisture content in biomass, the lower the yield of bio-oil produced. The bio-oil volume results in Figure 4 show fluctuating results. These results are not yet following the literature obtained, possibly depending on the condition of the pyrolysis apparatus and the state of running.

The results of the bio-oil pH test are shown in Figure 5 that at 100–200 °C pH tends to increase, while at 200–300 °C tends to decrease. The pH of the bio-oil produced has an average value of 2.77 with the lowest value being 2.48 and the highest being 2.91. This value is already per Dynamotive's [2016] bio-oil standard which is 2.3–3.3.

Bio-oil produced at 100–200 °C still has impurities such as dust and water that have not been fully decomposed, so the bio-oil produced tends to have more alkaline content. This is because water vaporized at 100 °C will also condense through the condenser so that it mixes and increases in

bio-oil levels, resulting in high pH as in samples A and B [Sahrum et al., 2021]. Samples C, D, and E yielded that bio-oil produced at 100–200 °C has more acid than those at 200–300 °C.

The results of all five samples ranging from 200 °C to above 300 °C show a decrease in pH. The higher the temperature, the higher the acid and phenol content is produced, as the raw material of the biomass containing cellulose, hemicellulose and lignin in the pyrolysis process is decomposed [Fauziati et al., 2018]. The high acidity in bio-oil is due to the high content of lignin in raw materials. The higher the lignin, the greater the phenol, the smaller the pH.

The raw material composition of rubber wood and coconut shell affects the pH value of the bio-oil produced. Coconut shell bio-oil has a greater pH than rubber wood because coconut shell bio-oil has a lower acid content. As shown in Figure 5 that bio-oil at 300–350 °C has an increased pH from samples A to E. This has also been seen in GC-MS analysis where phenols content in bio-oil with temperatures of 300–350 °C in sample E are higher than in sample B.

Density is measured using a pycnometer and is the ratio of the weight to the volume of bio-oil [Sa'diyah et al., 2021]. Figure 6 shows a graph of the bio-oil density test at various temperatures.

The average density of each bio-oil produced by pyrolysis at 100–200; 200–300; and 300–350°C is 1.04; 1.07; and 1.06 g/mL respectively. The same result is found in studies conducted by Weerachanchai et al. [2007] where bio-oil density ranges from 1.0 to 1.2 g/mL. The resulting bio-oil density already resembles diesel at 0.833 g/mL [Tüccar et al., 2018].

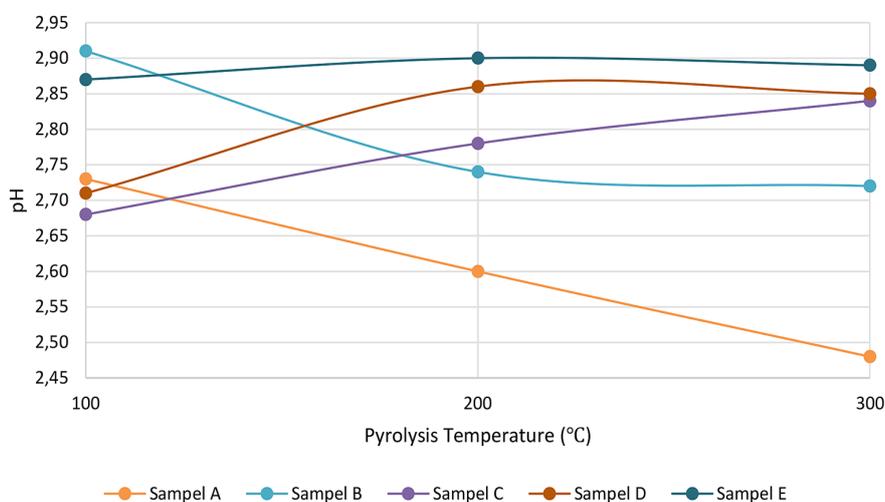


Figure 5. pH of bio-oil at various pyrolysis temperatures and raw material compositions

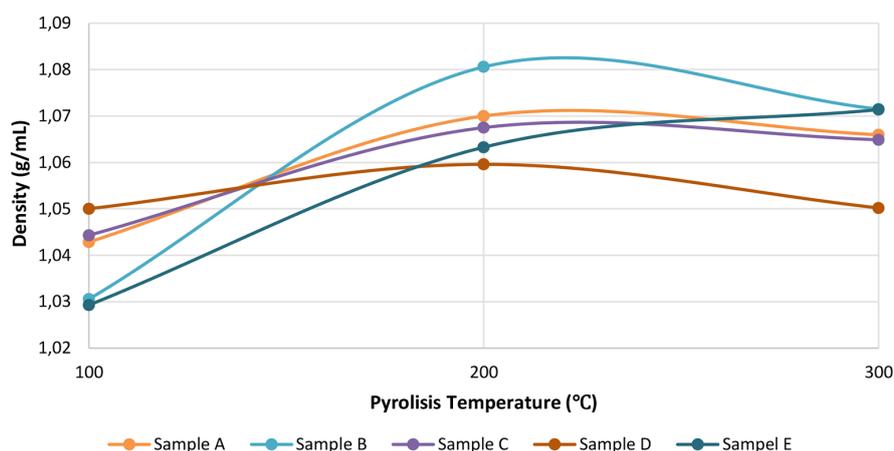


Figure 6. Density of bio-oil at various pyrolysis temperatures and raw material compositions

The graph shows the highest bio-oil density produced from a pyrolysis temperature of 200–300°C except for sample E which has the highest density at a pyrolysis temperature of 300–350°C. This is because most of the compounds already decomposed at 200–300°C. The density of bio-oil increases with increasing pyrolysis temperature as the breakdown of the biomass becomes more perfect and the precipitated tar will increase more [Diatmika, 2019].

The pyrolysis process in the study is continuous, this is one of the reasons that the highest bio-oil density is obtained at a pyrolysis temperature of 200–300, not at 300–350°C. The remaining raw materials in the reactor at 300–350 °C are almost fully decomposed, and the decomposed compounds in the bio-oil are also reduced. The lowest bio-oil density is found at a pyrolysis temperature of 100–200 °C because it still contains a lot of water. According to H. Sa'diyah et al., [2021] the maximum water drying or evaporation process occurs at 100 °C, while the decomposition of easily degraded compounds begins at 150°C.

Based on research conducted by Sakulkit et al. [2020] bio-oil from rubber pyrolysis has a water content of 63.17–73.36%. The water content of the bio-oil produced by the pyrolysis of coconut shells is 31% [Fardhyanti et al., 2017]. The presence of water levels comes from the pyrolysis of the biomass and the presence of little oxygen in the reactor resulting in combustion reactions producing water and carbon dioxide [Fardhyanti et al., 2018].

Research results suggest that increased rubber composition tends to increase bio-oil density. This is due to higher water levels of rubber

wood compared to coconut shells. The highest density is obtained in sample B with a composition of 80% rubber wood and 20% coconut shell. While for samples with 100% rubber wood has a slightly lower density, this is due to reactor leakage during research. This leakage results in combustion water vapor being wasted before condensation. The lowest density is obtained in samples D and E where the coconut shell composition is greater than that of rubber wood.

The viscosity of bio-oil is shown in Figure 7 and the resulting bio-oil viscosity on average of 1.45; 2.01; and 2.07 cSt for pyrolysis temperatures of 100–200; 200–300; and 300–350 °C. This shows an overall decrease in viscosity as the pyrolysis temperature increases. At high temperatures, molecular bonds between compounds in the fluid will be distanced from each other and cause bio-oil viscosity to decrease [Jayanudin et al., 2012]. The lowest bio-oil viscosity results from a pyrolysis temperature of 100 - 200 °C, this is because at that temperature most chemical compounds have not been decomposed and water vaporization is still present in the raw material. The highwater content of bio-oil decreases its viscosity [Romadani & Bahri, 2014]. According to the Bioenergy Directorate of EBTKE Indonesia (2020), diesel oil has a viscosity standard of 2.0–4.5 cSt. This indicates that the bio-oil research results have met the standard as a fuel in terms of viscosity.

The results of a study on the effect of raw material composition on viscosity show similar results to density. Where increased rubber wood composition tends to increase viscosity. This is due to the higher chemical content of

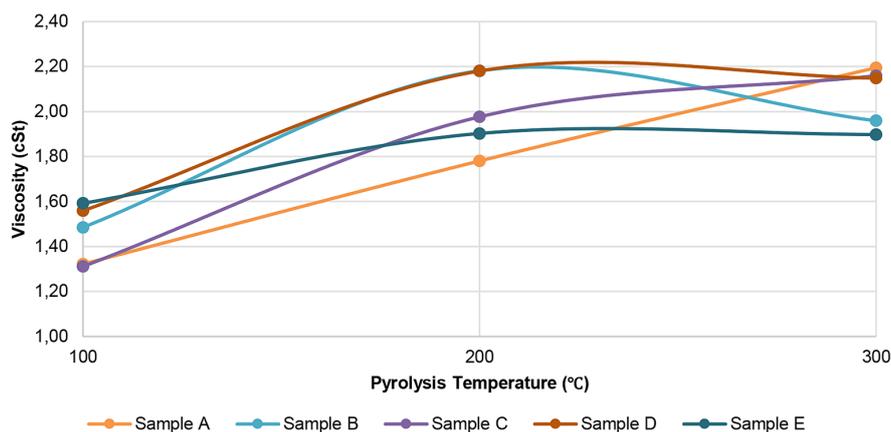


Figure 7. Viscosity of bio-oil at various pyrolysis temperatures and raw material compositions

rubber wood than coconut shells. The cellulose and hemicellulose content of rubber wood is higher than that of coconut shells. The average content of hemicellulose and cellulose in rubber wood is 17.81% and 46.36% respectively [Phumichai et al., 2020]. Coconut shells have 27.70% hemicellulose and 26.60% cellulose [Fardhyanti et al., 2017].

At 100–200°C pyrolysis temperatures, the results are inversely proportional, where the increase in the composition of the rubber wood decreases the viscosity of the bio-oil. This is influenced by the larger size of rubber wood compared to coconut shells as raw materials, so the time needed for water evaporation and decomposition are longer. The same result is shown by a study conducted by Zulkania [2016] where the larger the particle size of biomass will increase the viscosity of the bio-oil.

Gas chromatography and Mass Spectroscopy (GC-MS) analysis is performed to determine the compounds contained in bio-oil. An analysis is performed on samples B and E at 300–350°C as a representative of each raw material composition. The selection of both samples is because sample B has the highest rubber wood composition, as is sample E whose coconut shell composition is 80% respectively.

The results of GC-MS in both samples show that bio-oil has a complex compound contents. Visible bio-oil compounds consist of phenols, alcohols, ketones, aldehydes, hydrocarbons, and their derivatives. Biomass containing cellulose, hemicellulose, and lignin affects the chemical composition of bio-oil as individuals contribute to the chemical group [Machado et al., 2022].

Phenol and its derivatives along with furfural have the highest percentage in both samples. The same result was shown by a study by Fardhyanti & Damayanti [2017] that hemicellulose, cellulose, and lignin would be oxidized to phenolic compounds that are the main components of bio-oil. Cellulose and hemicellulose are thermochemically converted or degraded to anhydrous sugar (glucopyranoses) and heterocyclic components (furan, pyrans, and acids and derivatives). Lignin is the largest compound in phenolic components, such as phenols, methoxy phenols, phenolic aldehydes/ketones, low-molecular-weight phenols, and light oxygenates [Sakulkit et al., 2020]. Tables 2 and 3 along with Figure 8 and 9 show the results of GC-MS analysis on both samples.

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The high phenols than acid compounds are also affected by pyrolysis temperature, where when the temperature raised, the acid compounds will decrease while phenols will increase [Sun et al., 2023]. Phenols and their derivatives

Table 2. GC-MS results of sample B at 300–350 °C pyrolysis temperature

No.	Compounds name	Formula	%
1.	Phenol	C ₆ H ₆ O	18.78
2.	Furfural	C ₅ H ₄ O ₂	15.40
3.	2,6-Dimethoxy-phenol	C ₈ H ₁₀ O ₃	6.38
4.	2-Methoxy-phenol atau Guaiacol	C ₇ H ₈ O ₂	5.82
5.	2-Hydroxy-3-methyl-2-cyclopenten-1-one	C ₆ H ₈ O ₂	3.97
6.	3-Methyl-phenol	C ₇ H ₈ O	3.90
7.	2-Methoxy-4-methylphenol	C ₈ H ₁₀ O ₂	3.67
8.	2-Furanmethanol	C ₅ H ₆ O ₂	3.66
9.	4-Ethyl-2-methoxy-phenol	C ₉ H ₁₂ O ₂	3.55
10.	1,2-Benzenediol	C ₆ H ₆ O ₂	3.40
11.	2-Methyl-phenol	C ₇ H ₈ O	3.21
12.	1,2,4-Trimethoxybenzene	C ₉ H ₁₂ O ₃	3.16
13.	4-Ethyl-4-methyl-2-cyclohexen-1-one	C ₉ H ₁₄ O	3.06
14.	2-Methyl-2-cyclopenten-1-one	C ₆ H ₈ O	2.54
15.	3-Methoxy-1,2-Benzenediol	C ₇ H ₈ O	2.54
16.	Butanoic acid	C ₄ H ₈ O ₂	2.40
17.	1,2,3-Trimethoxy-5-methylbenzene	C ₁₀ H ₁₄ O	2.16
18.	1-(2-Furanyl)-ethanone	C ₆ H ₆ O ₂	1.95
19.	2,3-Dimethyl-phenol	C ₈ H ₁₀ O	1.86
20.	1-(Acetyloxy)-2-propanone	C ₅ H ₈ O	1.74
21.	2-Methoxy-4-(1-propenyl)-phenol	C ₁₀ H ₁₂ O ₂	1.74
22.	2(3H)-Furanone	C ₄ H ₄ O ₂	1.67
23.	2,3-Dimethyl-phenol	C ₈ H ₁₀ O	1.46
24.	2,3-Dimethyl-2-cyclopenten-1-one	C ₇ H ₁₀ O	1.01
25.	3-Ethyl-2-hydroxy-2-cyclopenten-1-one	C ₇ H ₁₀ O ₂	0.94
TOTAL			99.97

Table 3. GC-MS results of sample E at 300–350 °C pyrolysis temperature

No.	Compounds name	Formula	%
1.	Phenol	C ₆ H ₆ O	50.19
2.	Furfural	C ₅ H ₄ O ₂	10.92
3.	3-methyl-phenol	C ₇ H ₈ O	4.41
4.	2-methoxy-phenol	C ₇ H ₈ O ₂	4.19
5.	3-methyl-phenol	C ₇ H ₈ O	3.64
6.	2,6-dimethoxy-phenol	C ₈ H ₁₀ O ₃	3.37
7.	4-ethyl-2-methoxy-phenol	C ₉ H ₁₂ O ₂	2.16
8.	2-Furanmethanol	C ₅ H ₆ O ₂	2.14
9.	1-hydroxy-3-methyl-2-cyclopenten-1-one	C ₆ H ₈ O	1.79
10.	2,5-dimethylphenol	C ₈ H ₁₀ O	1.69
11.	2-Methoxy-4-methylphenol	C ₈ H ₁₀ O ₂	1.59
12.	1,2-Benzenediol	C ₆ H ₆ O ₂	1.40
13.	1,2,4-Trimethoxybenzene	C ₉ H ₁₂ O ₃	1.24
14.	3-methoxy-1,2-benzenediol	C ₇ H ₈ O	1.21
15.	2(3H)-Furanone	C ₄ H ₄ O ₂	1.20
16.	2-methyl-2-cyclopenten-1-one	C ₆ H ₈ O	1.20
17.	1-(2-furanyl)-ethanone	C ₆ H ₆ O ₂	1.03
18.	5-tert-Butylpyrogallol	C ₁₀ H ₁₄ O ₃	1.03
19.	Benzaldehyde	C ₇ H ₆ O	1.02
20.	2-methoxy-4-(1-propenyl)-phenol	C ₁₀ H ₁₂ O	0.94
21.	1-(acetyloxy)-2-propanone	C ₅ H ₈ O	0.88
22.	2,3-dimethylphenol	C ₈ H ₁₀ O	0.77
23.	Butanoic acid	C ₄ H ₈ O ₂	0.73
24.	2-Propenamide	C ₃ H ₅ NO	0.69
25.	2,3-dimethyl-2-cyclopenten-1-one	C ₇ H ₁₀ O	0.59
TOTAL			99.97

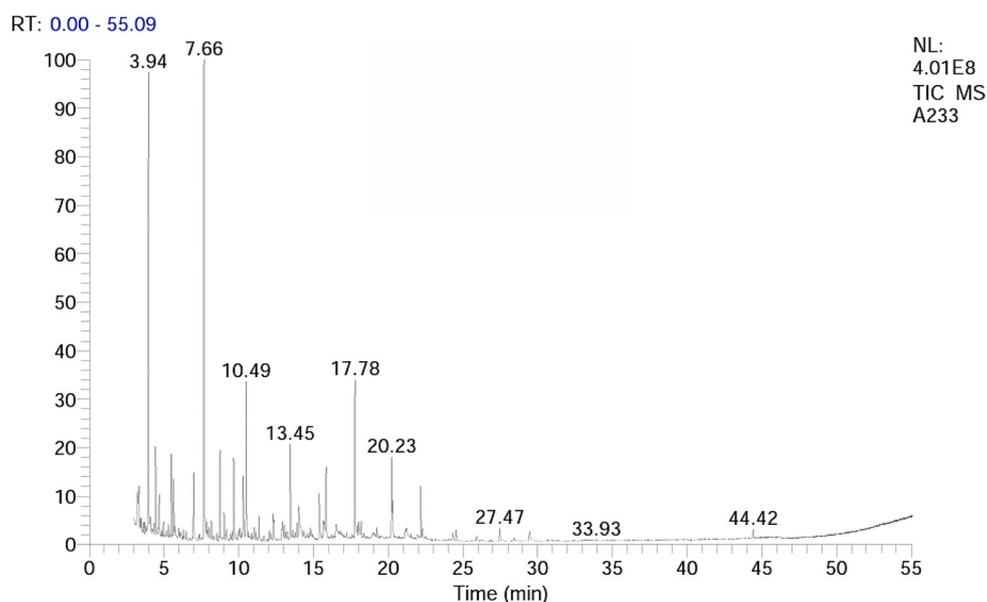


Figure 8. GC-MS results of sample B at 300–350 °C pyrolysis temperature

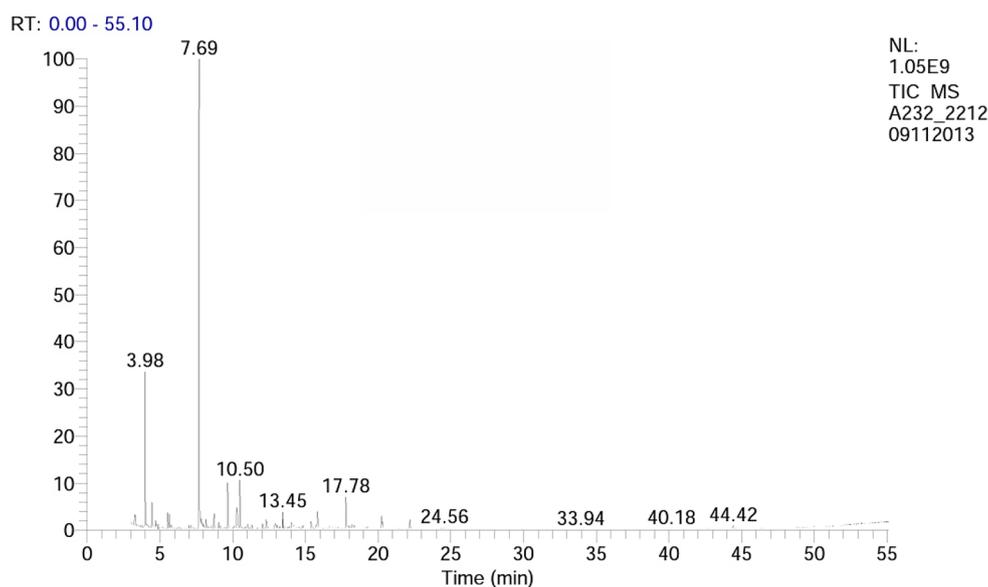


Figure 9. GC-MS results of sample E at 300–350 °C pyrolysis temperature

such as methoxy are the products of biomass pyrolysis [Patra et al., 2017]. The table shows that there are guaiacol derivatives such as 2,6-dimethoxy-phenol, 2-methoxy-phenol, 2-methoxy-4-(1-propenyl)-phenol that form at pyrolysis temperatures below 350 °C [Subagyono et al., 2021]. This was valid in this study because the analyzed sample was pyrolysis at 300–350°C.

The acid content of bio-oil is generally 2.8–9.5%. The acid content of rubber wood bio-oil is higher than coconut shell bio-oil. This is because the cellulose content in rubber wood is 45.67%, while the cellulose in coconut shells is 29.6% [Towaha et al., 2013]. Bio-oil has more lignin derivatives than hemicellulose and cellulose derivatives. This is also true of studies conducted by Subagyono et al. [2021] where at temperatures above 450 °C the total concentration of hemicellulose and cellulose derivatives is greater than lignin. High temperature rise of hemicellulose and cellulose derivatives occurs due to the continued decomposition of the derivative compounds formed at previous low temperatures (>450 °C).

At low temperatures or below 520–550 °C the compounds of hemicellulose and cellulose are decomposed into compounds with large molecules such as cyclopentanone and furanone. As pyrolysis temperature increases, large molecules such as phenol, furanone, and cyclopentanone in hemicellulose or cellulose break down and form smaller molecules such as acids, aldehydes, and furfural [Lyu et al., 2015].

The phenol content of coconut shell bio-oil is higher than that of rubber wood bio-oil due to the 41.72% higher content of coconut shell lignin than 16.69% [Towaha et al., 2013]. This is stated in Tables 2 and 3 where the results of GC-MS analysis on the phenol content of sample E is 50.19% higher than the phenol content of sample B, which is 18.78%.

High levels of phenol in bio-oil can be a potential bio-phenol that can be applied to various industries. A study conducted by Fardhyanti et al. [2019] showed that phenol in bio-oil can be extracted by liquid-liquid extraction using methanol solvents. Extraction of the compound will increase the efficiency of its application. Phenols are important compounds in the resin, paint, explosive, lubricating, pesticides, and plastics manufacturing industry. In addition, phenols can be used indirectly in plywood preparation [Shah et al., 2017].

The composition of bio-oil compounds we have analyzed can't be categorized in engine fuel characteristics due to the low caloric value, high water and oxygen levels, therefore bio-oil upgrading methods are needed to increase bio-oil application efficiency. The physical characteristics of bio-oil such as pH, viscosity, and density have met fuel characteristics. Research conducted by Jacobson et al. [2013] research on upgrading bio-oxygenation through hydrodeoxygenation to produce hydrocarbon-containing gases or diesel and may improve its chemical properties.

CONCLUSIONS

The temperature of pyrolysis has an influence on the characteristics of bio-oil, the higher the temperature will increase the volume of bio-oil produced. The largest density and viscosity is at a pyrolysis temperature of >200 °C. As the temperature increased, the value of density and viscosity decreased because the molecular bonds in them became distant. Whereas pH increased with increasing temperature due to increased acid content. Similarly to temperature, the composition of raw materials also had an influence on the characteristics of bio-oil. The higher the composition of rubber wood increased the volume, density, and viscosity as the water content and chemical compounds in rubber wood are higher than coconut shells. Meanwhile, more rubber wood compositions will lower the pH due to the lower acid content on the wood. According to the results of the GC-MS analysis conducted, phenol and its derivatives are the main compounds of bio-oil. The higher composition of coconut shells increased the phenol level in bio-oil due to its greater lignin content than rubber wood. Then, to obtain a quality bio-oil composition that has the highest phenol content of 50.19%, the bio-oil raw material composition is required in the form of 20% rubber wood waste and 80% coconut shell waste. The characteristics of bio-oil from the raw materials studied require further research to obtain high quality bio-oil. However, extraction and upgrading of bio-oil to remove other organic matters needs to be carried out with the aim of increasing the application of bio-oil on several industries and machines.

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