Original Research Article

Improving the quality of fast pyrolysis bio-oil (liquid fuel) using thermal distillation method

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ABSTRACT

Oil palm biomass generates an abundance via the oil palm industry such as Palm kernel shell (PKS), empty fruit bunch (EFB), frond, trunk. **Problem Statement:** The main issue nowadays is the global warming; one of the factors is the increment of CO2 content in the atmosphere. In order to reduce the CO2 content in the atmosphere, biomass is used, as it is a renewable, sustainable and cost-effective alternative energy source that needs to be adopted in the energy mix. The objective of this study was to improve the quality of bio-oil. **Approach:** In this research, empty fruit bunch (EFB) was utilizing in a fixed bed reactor, and pyrolysis oil upgraded via thermal distillation reactor. The temperature of pyrolysis was 500°C and the temperature of thermal distillation was 100°C. Gas chromatography mass spectroscopic, and ultimate analysis were utilized for investigation of chemical composition. **Results:** The maximum distilled bio-oil yield was 60- 65 wt. % at 100°C. The calorific value of bio-oil was 21 MJ/kg and distilled bio-oil was 30MJ/kg. The density of bio-oil was 1035 g/mL and distilled bio-oil was 980 g/mL **Conclusion:** The results showed that the distilled bio-oil obtained from EFB bio-oil have high calorific value and low oxygen content than, maybe it can use as fuel in engines.

Keywords: Biomass, Empty fruit bunch, Bio- oil, Distillation, Pyrolysis

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1. INTRODUCTION

Bio-oil is a liquid product of pyrolysis, with its colour properties being dark brown that consists of black liquid, often being characterized by the smoky odor. This bio-oil is a complex mixture of oxygenated compounds that consists of an amount of water that comes from the moisture inside the biomass itself. In addition to that, bio-oil also has a small amount of coal particles and alkali metals that have been dissolved during the pyrolysis chemical reaction. Generally, the composition of bio-oil depends on the parameters like, the types of biomass being used and also the operating conditions that are applied in the process. Besides that, the pyrolysis oil can be described as an aqueous micro emulsion that comes from the fragmentation of cellulose, hemicelluloses and lignin [1][2].

The dependency on the process conditions and the initial mass feedstock has a great effect on the properties of bio-oil being produced. Bio-oil is made up of 20–25% water, 25–30% water-insoluble pyrolytic lignin, 5–12% organic acids, 5–10% non-polar hydrocarbons, 5–10% hydro sugars, and 10–25% other oxygenated compounds[3]. The bio-oil produced from fast pyrolysis can be utilize directly without any upgrading as a fuel oil for combustion in boiler or a furnace. The viscosity of fast pyrolysis bio oil increased during storage, because of slow polymerization or condensation reactions [4]. Therefore, the bio-oil usage as fuels requires some methods of upgrading to improve storage stability and heating value.

One of the easiest ways to utilize of bio-oil for transportation fuel seems to be combine the bio-oil with diesel directly. However, the bio-oil from fast pyrolysis is immiscible with hydrocarbons, but it can be emulsified by using of surfactants by the ratios of 25, 50 and 75 % these emulsions were major stable than the original bio-oil [12]. Fast pyrolysis bio-oil also can be upgraded by hydro treatment using catalysts. The contents of oxygen significantly decrease by using catalysts, however this method is quite expansive and also the catalyst is easily deactivated[4].

Thermal Distillation of bio-oil from fast pyrolysis is a good method for upgrading bio- oil. This method preformed to improve heating value, corrosivity, and storage stability of fast pyrolysis bio-oil (liquid fuel).

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2. METHODOLOGY

2.1 Fast pyrolysis bio-oil preparation

Fixed bed reactor made of stainless steel was utilized to produce bio-oil via fast pyrolysis of EFB. The reactor dimension is 50cm height and 10cm in diameter. About 200 g of the biomass was the feedstock, placed in a batch reactor. This reactor is vertically positioned and N_2 gas was introduced inside the reactor at an injection amount/speed of 200 ml/min from the bottom, passing through the top of the reactor. The injection of nitrogen replaced the air from the reactor and allowed the pyrolysis reaction to take place under anaerobic condition. The vapour, as well as gases formed from the pyrolysis of the biomass inside the reactor, flowed out along with N_2 from the top of the reactor. The mixture of gas was passed through two condensers. The first condenser was cooled using dry ice, by which the vapour temperature was reduced to around 60°C, and the circulation of iced water reduced the temperature of the second condenser, where it was cooled to around 5°C. No vapour was seen to have escaped from the second condenser [5].

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2.2 Distillation of bio-oil

The method used to upgrade the bio-oil is via a reactor and stirring hotplate that will assist the distillation process through some modifications made. Firstly, put the bio-oil inside the reactor and provide heat of about 100°C with stirring hotplate. After that, pyrolysis bio-oil separated into tar and 10 fractions of bio-oil. The distilled bio-oil fraction yield is 60 - 65%. Figure 1 shows the Thermal distillation product yields from fast pyrolysis of bio-oil at temperature 100°C [6].

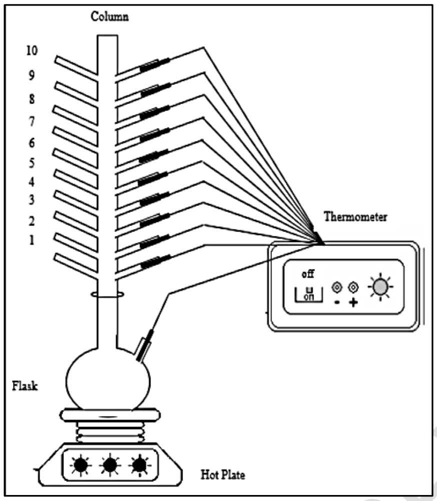

Fig.1. schematic diagram of the thermal distillation

2.3 Analytical Analysis

2.3.1 Ultimate Analysis

This analyser was used for the ultimate analysis, whereby in the biomass, the carbon, sulphur, hydrogen, and nitrogen percentages are obtained by calculating the oxygen's differences from the four elements. Thermo Fining Flashed model 1112 with helium gas as the carrier was used for the elemental analysis, and the ASTM standards (ASTM D5373-02) was carried out in accordance with the ultimate analysis. The organic material is homogeneous, where the carbon, nitrogen, hydrogen, and sulphur are determined using CHNSO series instruments. Also, a high-temperature combustion is used for the removal of the elements from the material. This combustion process runs on a normal 2 mg sample, encapsulated in a tin or silver capsule. The sample is then dropped into the furnace at the same time the oxygen is injected. The oxygen-rich environment is used to heat the sample; SOx, NOx, H2O, and CO2 are the CHNSO analysis products. These gases, which are carried through the system by helium carrier, are swept through the oxidation tube packed with copper sticks (which removes oxygen) to complete the conversion of SO2. The result is displayed as weight percent of C, S, N, and H of gases that were passed through four infrareds [7].

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2.3.2 GC-MS

GC-MS (Auto System XL GC/Turbo Mass MS, Perkin Elmer) with a quadruple detector and a DB-1MS capillary column (30 m × 0.25 mm inner diameter × 0.25 µm thickness) is used to test the bio-oil composition. As for the carrier gas, helium (UHP) is used at a constant flow of 1.2 mL/min. The primary temperature of oven temperature program was 40°C and the heating continued for 4 mins, rising by 5°C/min to 250°C, then continued to 10 mins. The bio-oil's chemical composition was tested using GC-MS (Auto System XL GC/Turbo Mass MS, Perkin Elmer) by a quadruple detector and a DB-1MS capillary column (30 m × 0.25 mm inner diameter × 0.25 µm thickness). Helium (UHP) was used as the carrier gas with a constant flow of 1.2 mL/min. The primary temperature of oven temperature program was set at 40°Cand continued for 4 mins, rising by 5°C/min to 250°C, which continued for another 10 mins. The injector temperature was 250°C. The volume of the injected sample (10% of bio-oil in chloroform) was 1 μL. Electron ionization (EI) was used in the MS and standard mass spectra with 70 eV ionization energy were recorded with a scanned range from 0 to 1200 amu. The computer recording matches the mass spectra that were performed using the NIST98 and WILEY7.0 library and the retention time of known species injected in the chromatographic column was used for identification of the peaks[8].

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3. RESULTS AND DISCUSSION

3.1 Characterization and chemical composition of bio-oil and distilled bio-oil

Table 1 shows the calorific value of distilled bio oil is much higher than fast pyrolysis bio oil compared with [3] research 17.5 MJ/kg. The distilled bio-oil water content is 17. 14 wt. % it is much lower than water content of fast pyrolysis bio oil, this finding is comparable with [9] studies. The pH of distilled bio oil is 2.95 it is much lower than fast pyrolysis bio oil 3.8 [10]. The oxygen content of distilled bio-oil is 34.7 wt. % which is lower than pyrolysis bio-oil 49. 20 wt. %. The decline of oxygen content in distilled bio oil is compared to the fast pyrolysis is much important because the high oxygen content in fuels transportation is not good[11]. Because of low oxygen content, high carbon and hydrogen content distilled bio-oil have higher heating value 30 MJ/kg. Table 1 shows the fast pyrolysis bio-oil properties. The pH value of bio-oil is 3.3. The low pH of bio oil represent that, there is a high probability of corrosivity than some metals [4]. The Density of bio-oil is 1035 g/mL which is higher than bio-oil fraction 980 g/mL. The calorific value of bio oil is 21 MJ/kg, and it is closer to[12] Finding around 23.48 MJ/kg it might be because of water content in the bio oil. The oxygen content of bio oil is 40- 50 wt. % it was closer to [13] studied bio oil 43.13 wt. %.

Properties	Fast pyrolysis bio-oil	Distilled bio-oil
H_2O (wt. %)	35- 50	17.14
pH	3.3	2.95
Density (g/mL)	1035	980
HHV (MJ/kg)	21	30
C (wt. %)	45- 49	58.8
H (wt. %)	5.0- 6.0	6.90
O (wt. %)	40- 50	34.7
N (wt. %)	0.02	0.19

Table 1. Properties of fast pyrolysis bio-oil and distilled bio-oil

GC-MS analysis was carried out with bio-oil to determine the type of possible compounds and nature in the bio-oil, and distilled bio-oil. Based on Table 2, fast pyrolysis bio-oil is a mixture of organic compounds which are including water, acids, and hydro cyclic substance. The fast pyrolysis of bio-oil contains 8.03 wt. % Benzene, (1,1-dimethylethoxy), 8.03 wt. % Phenol, 2,6-dimethoxy, 3.50 wt. % Phenol, 4-methyl, 8.80 wt. % Phenol, 3-methyl,8.58 and phenol,2,6- dimethoxy 3.90 wt.

Table 2 some composition of fast pyrolysis bio-oil and distilled bio-oil

Composition	Bio oil (wt. %)	Distilled bio-oil (wt. %)
Benzene, (1,1dimethylethoxy)	8.03	1.20
Phenol, 2,6-dimethoxy	3.50	2.56
Phenol, 4-methyl	8.80	1.43
Phenol, 3-methyl	8.58	1.60

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Phenol, 2,6-dimethoxy	3.90	1.50

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Table 2 shows distilled bio-oil is indicated the carbocyclic acid, and heterocyclic are much lower content than pyrolysis bio-oil, Benzene, (1,1-dimethylethoxy), 1.20 wt. % Phenol, 2,6-dimethoxy, 2.56 wt. % Phenol, 4-methyl, 1.43 wt. % Phenol, 3-methyl, 1.60 and phenol,2,6- dimethoxy 1.50 wt. The GC-MS analysis results show that the phenol derivative is the major group of compounds existed in both bio-oil, and distilled bio-oil. The highest area percentage for pyrolysis bio-oil was Phenol, 4-methyl 8.58, and for distilled bio-oil was Phenol, 2,6-dimethoxy 2.56 % [14].

4. CONCLUSION

Although the bio-oil obtained from different biomass have different compounds. These Bio oils have high oxygen content, and not stable and their compositions quickly change during storage. Fast pyrolysis bio-oil may use as fuels or source of chemical feedstock but, it needs some methods to improve the heating value, and storage stability. Thermal distillation is one of effective and sample method to reduce the oxygen content of fast pyrolysis bio-oil, distilled bio-oil is more stable compared than fast pyrolysis bio-oil. HHV of distilled bio-oil is 30 MJ/kg which is much higher than fast pyrolysis bio-oil.

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Comment [sk18]: Reference provided at serial no. [2] is incomplete.

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