Thermo Distillation and Characterization of Bio oil from Fast Pyrolysis of Empty Fruit Bunch (EFB)

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Abstract - **The demand for sustainable fuels on one hand and the shortage of conventional energy resources on the other hand, has led to the need for the development of alternative, environmental-friendly fuels. Hence, the objectives of the current study were to produce a liquid fuel (bio-oil) from Empty fruit bunch (EFB) and to characterizes the bio oil by fast pyrolysis method, in a batch feeding and fixed bed reactor. The Temperature was set to 500°C for all the distillation experiments and the bio oil was collected from the condenser. The total yield of bio oil based on EFB was 66wt.%. The non-condensable gases obtained from the process were CO_2, CO, CH_4, C_2H_6, C_2H_4, C_3H_8 and C_3H_6. The higher heating value (HHV) was 27 MJ/Kg. The physical and chemical properties of the produced oil was also determined and discussed in this paper.The moisture, volatile mater and ash were determined and found to be around 1.4391wt %, 6.0182wt% and 1.3906wt%respectively. The outcomes of this research demonstrated that the produced bio-oil could be considered as an eco-friendly fuel. However, further modifications are required to make it more efficient for industrial-scale (mass production) of EFB-produced bio oil in the near future.**

Keywords **-** Biomass Pyrolysis, Thermal Distillation, Bio oil, Fraction of Bio oil, Empty fruit bunch

I. INTRODUCTION

The energy is among the most influential factors in the development of today's world and it is one of the main concerns for the future of mankind. Nowadays, 85% of energy demand energy is fulfilled by depletable fossil fuels [1]. However, there are several types of renewable energy sources such as solar energy, wind energy, biomass energy, tidal power, that is expected to compensate for a huge proportion of our current energy usage in the near future.

Biomass, which could be any forms of organic substance that is used as fuel, has been a focus of attention in the recent years due to its environmentally-friendly nature and fuel replacement values [2-3]. Organic substances such as feedstock from plants municipal solid west (MSW), municipal bio solids (sewage), and animal wastes (manures) the agricultural residues and certain types of industrial wastes could be considered as biomass. Biomass can produce enough energy to be used as a replacement of fossil fuel[4]. Biomass solids could be converted to the liquid fuel by pyrolysis and to the combustible

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Received : 15 November 2017
Accepted : 31 December 2017
Published : 31 December 2017

gases by gasification. These products can be used in engine and turbine for power generation[5].

Bio-oil is a liquid product of pyrolysis, which is a dark colored liquid, often characterized by its smoky odor. This bio-oil is a complex mixture of oxygenated compounds that consists 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 such as the types of biomass being used as the feedstock and the operating conditions that are applied in the processes [6-7].

The agriculture sector in Malaysia has been rapidly growing, which has led to production of a vast amount of agricultural wastes [8]. The most important product in the agricultural sector of Malaysia is the palm trees plantations. Around half of the world's palm oil production (10.8 million tons) comes from the palm oil produced in Malaysia [8]. Around 85% of palm oil in the Southeast Asia is used as palm oil feedstock in the production of biodiesel and various products in Malaysia and Indonesia. In 2010, approximately 48.537 km^2 (4,853.7 ha) or 14.72% of the land was used for palm oil plantation, having an approximately 135-145 trees planted, per hectare [10]. Therefore, the amount of the waste produced by this industry is enormous. Empty fruit bunch, being one of those major solid wastes. Hence, the aim of this study is to investigate the potential use of empty fruit bunch (EFB) as a source of bio mass to produce bio-oil as an environmental friendly alternative fuel. If EFB can be used in a large scale, it can mitigate both the amounts of the agricultural wastes from the palm oil industry as well as being an economically feasible source of new clean fuel.

II. EXPERIMENTAL

2.1 Feed Stock Preparation

The raw EFB was obtained from the palm oil mill located in Klang, Selangor, Malaysia. The proximate and Elemental analysis of EFB was summarized in Table1. However, due to the high moisture contents of the feedstock, the produced bio oil has also significant moisture content. The first feedstock was dried in the dryer for more than 48 hours. As a result, moisture content dropped to 23 wt.% from the initial value of 57 wt.%, which was still significant. Table 1 summarizes various analysis of EFB and the bio oil.

Table 1: Proximate and Elemental analysis of EFB

Particle size (mm)	**10-12 mm**
Heat value (HHV) (MJ/Kg)	20- 21MJ/Kg
Proximate analysis of EFB	
Moisture content	7.68
Volatile fraction (wt%)	12.05
Ash content (wt%)	17.92
Elemental Analysis of EFB	
N	1.77
C	35.47
H	6.08
S	0
Proximate analysis of EFB Bio oil	
Moisture content	1.43
Volatile fraction (wt%)	6.01
Ash content (wt%)	1.39

2.2 Fast Pyrolysis Procedure

Bio oil produced from EFB in a laboratory scale, in a fixed bed reactor. The dimensions of the reactor was 50 cm height ×10 cm in i.d. A 6kg batch of EFB was fed in into the reactor. The reactor was positioned vertically and N_2 was introduced from the top of the reactor at the rate of 200ml/min. N_2 was used to displace(remove) the air out of the reactor and to create anaerobic conditions that is necessary for the pyrolysis reaction. The formed vapor and gases, which resulted from the pyrolysis of EFB inside the reactor, flows out along with N_2 from the top of reactor. The pyrolized gases were then passed through the condenser. The condenser was cooled with ice and reduces the vapors temperature to around -5±0.5 °C. The liquid bio oil product was than collected in conical flask. The drying temperature was at 50°C and the batch had lasted for 48 hours in the drier to reduce the moisture content. The biomass was inserted into the reactor; the fire was then introduced. After that, the air and nitrogen also injected at about 200ml/min at a stabilized temperature of 500°C. The pyrolysis of the raw material took about 30 minutes and gradually, after 30 minutes, the bio-oil is collected. The pyrolysis products were bio oil, bio char, and gases. Figure 1 illustrates the schematic of apparatus used in this research.

2.3 Thermal Distillation Procedure

The method used to upgrade the bio-oil is via a reactor and stirring hotplate that will assist the distillation process. Firstly, the bio-oil was placed inside the reactor and provides heat of about 100°C with stirring hotplate. After that, the effluents were collected in 10 fractions. The temperature ranges between fractions were 49- 102°C.

2.4 Analytical Methods

FTIR spectroscopy was conducted on the bio oil sample to determine the composition of the oil. The structural changes of bio-oil as a function of different sample preparations (pre-treatment process) is also investigated and applied by this instrument. In this research, FTIR is performed by using Perkin–Elmer Spectrum 2000 FTIR with the wavelength of 4000 – 600 cm^{-1}.

The second analysis conducted was 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) that was also utilized to determine the bio-oil composition. As for the carrier gas, helium (UHP) was 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). The computer recording matches the mass spectra that was performed using the NIST98 and WILEY 7.0 library and the retention time of known species injected in the chromatographic column were used for identification of the peaks.

2.5 Physical Characterization of Bio Oil

The density of bio oil was measured with a using Hydrometer. Viscosity was measured by viscose meter (35SA). A digital pH meter manufactured by mettler toledo™ was used to obtain the pH. Calorific value of bio oil was estimated via bomb calorimeter. Water content of the bio oil was measured by water analyzer (Satorius™ Model- MA35). All the analysis are shown in Table 1.

III. RESULTS AND DISCUSSION

The physical and chemical properties of the feed stock play an important role in the yield and its properties. Therefore, the EFB feed stock and bio oil was characterized to know the physical properties and chemical composition, as shown in Table 1. Initially, the biomass has around 50 wt% moisture;

however, after putting in the dryer for 24 hours, the moisture contents is reduced to around 23 wt%, for the biomass and 12% for the bio oil, respectively.

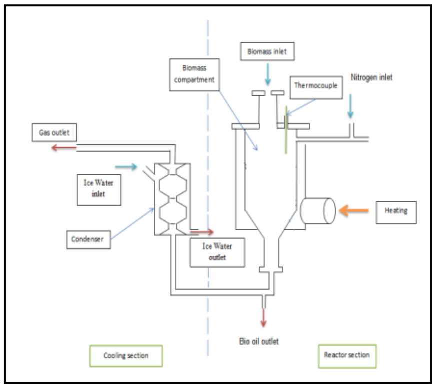

Fig. 1 Schematic diagram of bio-oil produced via fast pyrolysi

The bio oil fraction moisture is shown in Table 2. The high water content of the bio oil is due to the high moisture content of the feedstock, which as a results leads to high moisture contents in the product. Particle size and the surface area plays a major role in the yield content [12]. Thus EFB was crushed to the particle size of about 0.5-1.0mm size via grinding machine. The density of bio oil was 1.04 g/mL at 25°C. The higher heating values (HHV) of bio oil ranged from 20-21 MJ/Kg [13]. The energy content of bio oil extracted was half of that of diesel with energy content 43.097MJ/Kg, which is still a considerable amount of energy[14]. The fractions of bio oil properties are shown in Table 2.

Table 2: Moisture contents Bio oil Fractions

No	Fractions of EFB Bio oil	Moisture 105°C/ 3 min		Temp. of Fractions
		%	Weight / gr	
1	1	59.74	0.493	102
2	2	30.21	0.472	97
3	3	34.08	0.497	96
4	4	24.54	0.492	91
5	5	20.11	0.543	93
6	6	20.15	0.542	85
7	7	25.00	0.480	78
8	8	27.55	0.476	63
9	9	30.33	0.536	56
10	10	20.99	0.487	49

3.2 Chemical characterization of bio-oil and fraction of bio oil

The total yield of bio oil from the feedstock was around 66 wt.%. Prior to the drying process, the solid feedstock of EFB weighted around 6 kg. However, it had gone down to 4.594 kg post process, which is around 23 wt.% reduction.

The proximate analyses of EFB, and the bio oil extracted from EFB were preformed and the results are summarized in Table 1. Proximate analysis was conducted to determine the moisture content, concentrations and composition of the volatile components, fixed carbon and ash content. Dried biomass of EFB and bio oil contains about 1-7% of moisture, volatile mater about 6-12%, and ash about1- 17%. EFB bio oil has low volatile, moisture and ash. FTIR spectra of the bio oils from pyrolysis of EFB at 500 °C are shown in Figure 3. It can be seen that the bio oil derived from EFB has similar characteristics and a large of oxygenated organic compounds. stretching vibration between 3356- 3400cm^{-1} which resulted from The O-H indicated the presence of phenol and alcohols, whereas the C- H stretching vibration between 2924- 2930 cm^{-1} specified the presence of Alkanes. Moreover, the C=C stretching vibration between 1637- 1650 cm^{-1} showed the presence of conjugated alkene. The N-O stretching vibration between 1502- 1550 cm^{-1}indicated the presence of nitro compounds[15]. The C-H bending vibration between 1466- 1470 cm^{-1} indicated the presence of alkane[16]. For case of C-H deformation vibration in range of 1240- 1400 cm^{-1} is an indication of the presence of alkanes which is possibly due to C-O vibration from carbonyl compounds (i.e.

alcohols, carboxylic, acids, ether and esters) of bio oil from EFB occurred in range of 1104 and 1200 cm^{-1}[17].

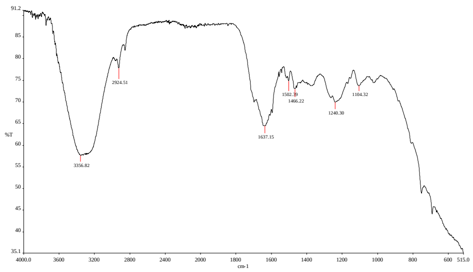

Fig. 3 FTIR spectra of bio oil

GC-MS analysis was carried out on the bio oil and the possible compounds in fractions was determined. The GC-MS analysis showed that bio oil fraction includes of a wide variety of organic compounds such as CH_4, C_2H_6, C2H4, C_3H_8 and C_3H_6. Most of the fractions of bio oil were oxygenated, which showed high oxygen content in the bio oil fractions. This compounds decrease the HHV which decreases the quality of the bio oil to be used as fuel utilization and transportation (such as diesel). Nevertheless, it is still possible to reduce this oxygenated components using modification methods such as hydro-treating and/or hydro-cracking.

IV. CONCLUSIONS

EFB Bio oil was produced from pyrolysis of Empty fruit bunch in a fixed bed reactor at 500°C. The vapors condensed and collected in a condenser. The non- condensable gases were CO_2, CO, CH_4, C_2H_6, C_2H_4, C_3H_8 and C_3H_6.. For HHV of bio oil using temperature bomb calorimeter above 550°C. In the 500°C aqueous phase of bio oil the HHV could not be readily determined due to the very high amount water content[11]. The bio oil fractions were produced in a thermo distillation reactor in 100°C. The ten fractions of bio oil were condensed and collect in the columns. The fraction of bio oil organic compounds in 100°C was perfectly ignited. Therefore, the EFB bio oil could be considered as bio oil to be used in the future. However, further studies are required to reduce its moisture content.

ACKNOWLEDGMENTS

The authors would like to thank Faculty of chemical engineering (FKK) of Universiti Teknologi Mara (UiTM) to provide materials and apparatus that made this research possible.

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