Fractionation of Bio-oil using Fractional Distillation Column for Transportation Liquid Fuels

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***Abstract*— The advancement of technology in transportation industries has been booming and the demands of fossil fuels is at its peak and need to be fulfilled. But conventional fuels such as petroleum and diesel will eventually be depleted in time and an immediate alternative solution is needed to meet the demands for fossil fuels. Introduction of bio-oil will serve as a new substitute for conventional fuels where it emits less pollution emission and act as renewable resources. Thus, the aim of this research is to produce bio-oil from Palm Kernel Shell (PKS) and Empty Fruit Bunch (EFB) by Fast Pyrolysis. The resulting crude bio-oil produced is cooled and collected before being sent for separation process (Fractionation Distillation). A total of 10 fractions of liquid bio-oil from the column is examined and analysed through physical and chemical analysis. Through physical analysis, the water content especially in the upper fraction of the column for EFB is higher than that in PKS bio-oil samples, and both PKS and EFB bio-oil pH values behaviour shows high degree of acidity level. In chemical analysis method, Fourier Transform Infrared Spectroscopy (FTIR) is used to detect functional groups in PKS and EFB bio-oil samples. Unlike EFB bio-oil analysis, PKS shows higher margin of deviation due to its temperature sensitive difference but still both produces rather similar trend of analysis. Lastly, Gas Chromatography-Mass Spectrometer (GC-MS) is used to identify numerous chemical composition of PKS and EFB bio-oil constituents.**

Keywords*— *Fast Pyrolysis, Palm Kernel Shell (PKS), Empty Fruit Bunch (EFB), Fractional Distillation (DC), Fourier Transform Infrared Spectroscopy (FTIR), Gas Chromatography-Mass Spectrometer (GC-MS).

1. INTRODUCTION

The introduction of bio-oil fuels from biomass feedstock as raw material has been a turning point and an immediate solution to replace existing conventional fossil fuels such as gasoline, and diesel used as transportation fuels. Since conventional fossil fuels is non- renewable resources, then bio-oil fuels served as an immediate solution for generating more than approximately 1.5 billion vehicles running currently in worldwide (S. Edelstein, 2017).

But direct use of crude bio-oil is not recommended yet since there are several properties of bio-oil that are not suitable for transportation fuels. According to Majhi, et al. (2013), high water and oxygen content, high acidity and low heating values has been a drawback for the direct application of crude bio-oils and an upgrading method is introduced further in this journal such as Fractional Distillation Column. This is mainly to heat crude bio-oils into certain fractions in the column and identify which fraction is bio-oil riched suitable as Second-Generation transportation fuels.

A detailed analysis process of identify the types of component present in upgraded bio-oils was done using powerful analytical equipment such as Gas Chromatography-Mass Spectrometer (GC-MS) and Fourier Transform Infrared (FTIR). This will provide great accuracy of component profiling in terms of peaks as data and directly matched the component with existing databases, which is also extensively used in pharmaceutical industry and medicine manufacturer (Elliott, et al., 2013).

2. PRODUCTION OF BIO-OIL

2.1 Characteristics of Crude Bio-oil

The distinctive characteristics of bio-oil are it is consisting an approximately 200 types of organic compound and dark brown in colour. Crude bio-oils is the product of degradation of lignocellulosic biomass that is comprised of cellulose, hemicellulose and lignin as the three main structural blocks (Ehsan Reyhanitash, 2013). Thus, each of the main blocks above is responsible and to be determined the quality of a good bio-oil as transportation fuels.

Fig. 1: The bio-oil produced is mostly organic and dark brown in colour.

2.1.1 Cellulose component.

Generally, cellulose component is the basic skeletal constituent of wood cell walls which contributes to an approximation of 40 - 45 weight % of dry wood; whereby glucose anhydride is formed via removal of 1 mole of water from 1 mole of glucose. During fast pyrolysis process at temperature of 240 – 350 °C, this cellulose will degrade and the long carbon chains of cellulose is broken down (Reyhanitash, 2013).

2.1.2 Hemicellulose component.

Second biggest constituent component compared to cellulose, which consist of 23 – 35 weights % of dry wood. Ehsan Reyhanitash (2013) reported that the hemicellulose is made from a very long chains of saccharides unit up to almost 150 units, thus leading to lower molecular weight than that in cellulose component. Unlike cellulose, hemicellulose component degrades at much lower temperature (200 – 260 °C) and rapidly vaporized from the fast pyrolysis reaction.

2.1.3 Lignin component.

Lignin is the third major constituent of wood behind hemicellulose and cellulose component. It is responsible to almost 24 - 33 weight % of dry wood; provides mechanical strength and resistance to biological degradation for plants. During fast pyrolysis process of high temperature of over 500°C, lignin degrades into phenols through decomposition of ether and carbon-carbon bonds, thus producing higher solid char yield as end product (Reyhanitash, 2013).

2.2 Primary Sources of Bio-oil

2.2.1 Municipal Solid Waste (MSW).

Municipal Solid Waste (MSW) has currently been a main source for biomass raw material in Malaysia as the country population is expanding, so as the amount of MSW produced as end product. But sanitary landfill has negative influences for the environment as deforestation and flatting of land is needed at large area, thus more spaces is occupied for MSW storage. Thus, in order to reduce the number of landfills, the MSW will be utilize for electrical power generation where MSW is fed as bio-fuels for power plant.

2.2.2 Empty Fruit Bunch (EFB).

For empty fruit bunch (EFB), the raw material is collected from the oil palm tree, dried to separate moisture content and crushed before being formed into cylindrical pellets form. In Indonesia region, they are the largest crude palm oil producer in the world where an average production scale of 2.35 x 10^{13} kg per year and for each kg of palm oil roughly another 4 kg of dry biomass are produced. This results an almost 7.8 x 10^{6} g of EFB was available annually for renewable energy source (Sembiring, et al., 2015).

2.2.3 Palm Kernel Shell (PKS).

Palm kernel shell (PKS) from oil palm trees is most abundant materials in moist tropical climate country such as Malaysia. This is an advantage to the country whereby a continuous supply of PKS is readily available and sold at a cheap cost of raw materials; since Malaysia is also one of the main producers of palm oil in East Asia region and contributes as the country main economic incomes. For this research purpose, PKS and EFB is extensively used throughout the experiment to compare the physical and chemical properties and quality specifications of each crude bio-oil production.

2.3 Application of Bio-oil Production

2.3.1 Electrical Power Grid Generation.

Using upgraded bio-oil, the main beneficial application is the generation of electricity to supply the power grid. Especially with the rapid increasing in consumer electrical energy demands globally, it is essential to conserve and generate clean energy. Malaysia has also been monitoring these progress of bio-electric generation and Tenaga Nasional Berhad (TNB) Company are currently focusing on using biomass feedstock as their main fuels rather than using non-renewable charcoal and natural gas fuels. Mentioned by Academy of Sciences Malaysia (2013), BioGen is an example of project conducted by TNB to promote biomass and biogas grid-connected power generation which can approximately generate 13MW of electricity.

2.3.2 Transportation Fuels.

Bio-fuels has been introduced as the future Second Generation Transportation fuels than the conventional petroleum and diesel fuels. As conventional fuels are a non-renewable energy and is depleting from natural resources, an alternative is needed to counter the shortage of fuels and bio-fuels shows great potential in generating billion of transportation vehicles on the streets around the whole world (BTG-BTL Company, 2016). Current establishment is the production of bio-diesels made from Jatropha Oil and Palm Oil, with minimum Greenhouse gases released to the environment and more eco-friendly products. A constant blending process of bio-oil with certain fossil fuels are also recommended to upgrade the quality of bio-oil as transportation fuels.

2.3.3 Sources of Fuel for Boilers.

Upgraded bio-oil fuels have also been tested for industrial boilers and gas turbine generator as fuel feed. This is to minimize the dependency of other conventional fuels such as diesel and natural gases during combustion in the boilers, thus less hazardous gases emission can be generated (Spyros Kyritsis, 2001).

2.4 Pyrolysis Process

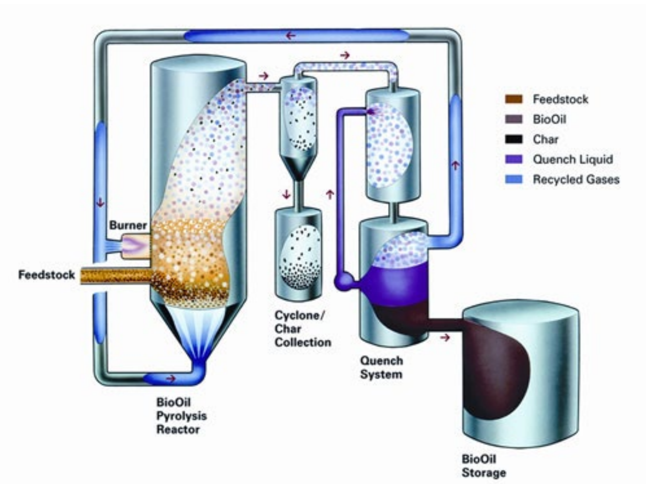

Fig. 2: The schematic diagram for Fast Pyrolysis process.

Pyrolysis process is a thermochemical process which involves introducing a very high temperature of 500 °C into a reactor (Pyrolyzer) without the presence of oxygen (air sealed system). Biomass raw material such as EFB or PKS will be degraded into condensable and non-condensable gases. The condensable gas is quickly cooled using cooling medium such as ice packets into crude bio-oil while the non- condensable gases will be burnt as flame exhaust gases (undesired side product). In general, there are two types of pyrolysis process which is the slow pyrolysis and fast pyrolysis. According to Seung-Jin Oh, Gyung-Goo Choi, and Joo-Sik Kim (2016), these two processes is different in temperature, heating rate and vapour residence time on operating condition. Thus, numerous parameters can be analysed and tested to determine which of these two processes is effective for crude bio-oil production.

In order to achieve high yields of liquid crude bio-oils, the temperature must be set to 500 °C where minimum or no solid bio chars and low concentration of non-condensable gases is achieved. This heating value must be at optimum and at short residence time (seconds), thus more condensable gas can be cooled and collected as crude bio-oils. For this research project, fast pyrolysis is chosen as desired process selection that is coupled with a fractional distillation column (upgrading method) to further purify the crude bio-oil to high quality bio-oil.

3. UPGRADED METHOD OF BIO-OIL INTO VIABLE TRANSPORTATION FUELS.

Fractional Distillation Process is a common liquid-liquid separation which involves separation based on component's boiling point (volatility), thus certain fraction of liquid products can be obtained at different temperature intervals. According to Shurong Wang (2011), atmospheric pressure distillation, vacuum distillation, steam distillation, and some other types of distillation have been applied in bio-oil separation. Each of the distillation used have their advantages and disadvantages during crude bio-oil upgrading treatment.

To further detailed this research, Fractional Distillation Process is used as the upgrading system for crude bio-oils produced by Fast Pyrolysis. This is to remove certain unwanted fractions such as acidic compounds, water and oxygen content and improves the heating values of the upgraded fraction of bio-oils (J. Mikulec, J. Cvengros, et al., 2010).

4. METHODOLOGY

4.1 Materials

The material used for this research project is Palm Kernel Shell (PKS) and Empty Fruit Bunch (EFB) granules feedstock that to be used in producing crude bio-oil via Pyrolysis process respectively. The both crude bio-oil from both PKS and EFB will undergo fractional distillation to separate the components into fractions through boiling point difference. In addition, the fractionated PKS and EFB samples will be further analyzed through physical and chemical analysis method.

4.2 Methods

With the fractionated bio-oil is collected via Fractional Distillation method, detailed analysis is conducted in order to identify the physical and chemical properties of the resulting upgraded bio-oil.

4.2.1 Physical Analysis Method

4.2.1.1 Water Content Analysis via Karl Fischer method.

The water content in each PKS and EFB bio-oil fractions can be determined to highlight which fraction has lower water content (better bio-oil quality) that can be extracted using Karl Fischer method.

4.2.1.2 pH Values Analysis via pH Meter method.

To test the degree of acidity of bio-oil, pH values need to be recorded using pH meter and check the pH values behavior of the fractions throughout the column.

4.2.2 Chemical Analysis Method

4.2.2.1 Functional Group Determination Using Fourier Transform Infrared (FTIR).

Specific functional groups can be identified using FTIR analysis whereby it will generate a pattern profile of matched chemical compounds and shows the peaks (wavelength) of any functional group exist inside both PKS and EFB samples (Intertek Group, 2015).

4.2.2.2 Chemical Composition Analysis via Gas Chromatography-Mass Spectrometer (GC-MS).

GC-MS is an important analytical instrument with a very high accuracy of detecting compounds with a low detection limit. Since bio-oils have more than hundreds of organic compounds in its composition and GC-MS is suitable instrument to detect components in data forms of Total Area Percentage and Retention Time.

5 RESULTS AND DISCUSSION

5.1 Water Content Analysis via Karl Fischer method

For Palm Kernel Shell (PKS) bio-oil, the water content is measured in millilitres (ml) and shows rapid decreasing of water content from the first fraction to the tenth fraction. This shows that water which has higher boiling point than bio-oil tend to accumulate at the lower fraction of the distillation column.

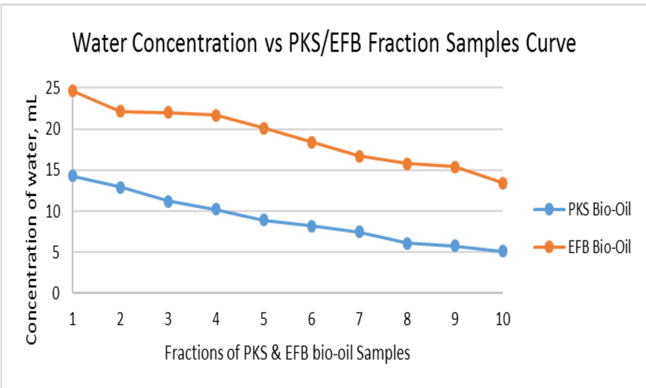

Fig. 3: The water concentration against the number of fraction for EFB & PKS bio-oil.

For EFB bio-oil, the water content shows steady decreasing in amount from the first fraction until the last tenth fraction of the distillation process. But compared to PKS, EFB still has higher water content than PKS and shows poorer quality of bio-oil that might be produced based on this trend.

In conclusion, high volume of water is present in lower fraction of fractional distillation apparatus for both PKS and EFB bio-oil samples. Both samples show decreasing amount of water from lower fraction to the higher upper fraction. Thus, the quality of the bio-oil depends on the water content present in bio-oil at the upper fraction of the distillation column. This may affect the application of bio-oil in transportation fuels.

5.2 pH Values Analysis via pH Meter method

For EFB bio-oil in Figure 4, the pH values show medium fluctuation whereby from the first to third fraction, the pH values are declining (becoming more acidic) before maintaining a steady pH values from the fourth fraction to ninth fraction. Subsequently, the pH value increases at the tenth fraction to the final pH value of 3.23. For PKS bio-oil samples, the pH values are more stable and consistent from the first fraction to the ninth fraction at an average of 2.5 pH values before rapidly increased to pH value of 2.6.

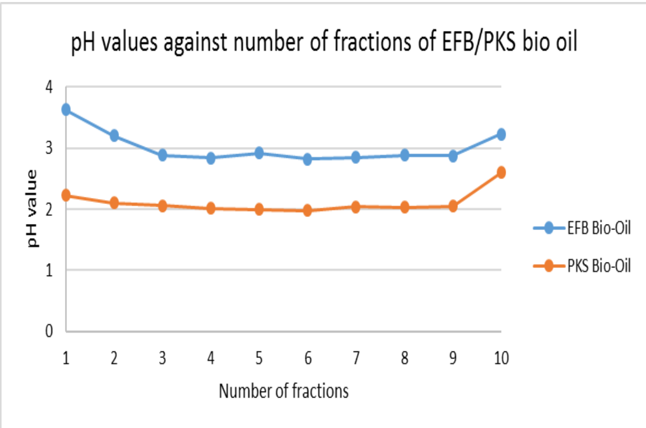

Fig. 4: The pH values for both PKS and EFB bio-oil samples in ascending number of fractions.

In conclusion, PKS bio-oil fractions shows higher acidity (lower pH values) compared to its counterpart, EFB bio-oil fractions. Thus, in order to minimize the level of acidity of a suitable upgraded bio-oil, the EFB is preferable although both EFB and PKS still shows signs of high acidity (PKS with average pH values of 2.5 and EFB with an average pH values of 3.01 respectively). This information is supported by journal statements from Shuangning Xiu and Abolghasem Shahbazi (2016) on Bio-oil production and upgrading research: *A review. Renewable and Sustainable Energy Reviews.*

5.3 Functional Group Determination Using Fourier Transform Infrared (FTIR)

5.3.1 *Empty Fruit Bunch (EFB) Functional Group Analysis.*

Based on the Figure 5, EFB Bio-oil shows minimum deviation of functional group in each fraction in respect with different temperature of fractions incurred. The patterns are almost similar to each other with the presence of 5 different peak bands categorized according to their wavelengths.

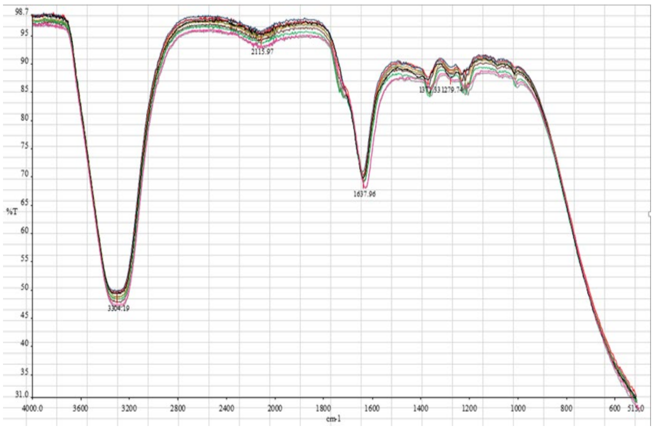

Fig. 5: The overall peak analysis of all 10 fraction of EFB based bio-oil according to their wavelengths.

The first peak at 3304.19 cm^{-1} belongs to the Alkynyl, Alcohol Phenol, Aromatic and Amine group. Next, the second peak at 2115.97 cm^{-1} are identified as Alkynyl group and the third peak of 1637.96 cm^{-1} are Aromatic and Amide group respectively. Lastly both the fourth and fifth peaks of 1371.33 cm^{-1} and 1279.74 cm^{-1} belongs to Mono and Polycyclic Aromatic.

5.3.2 *Palm Kernel Shell (PKS) Functional Group Analysis*

For PKS bio-oil fractions, there are a total of 4 potential peaks that is obtained through FTIR analysis. The first peak of 3349.95 cm^{-1} is identified as Alcohol/Phenol, Amine and Alkynyl group. Moreover, the second peak of 1640.68 cm^{-1} belongs to the Alkenyl, Aromatic and Amide group, responsible as main component for good quality bio-oil. Finally, the third and fourth peaks of 1387.50 cm^{-1} and 1273.62 cm^{-1} can be categorized as C-O-C group which is the derivative functional group in bio-oil samples.

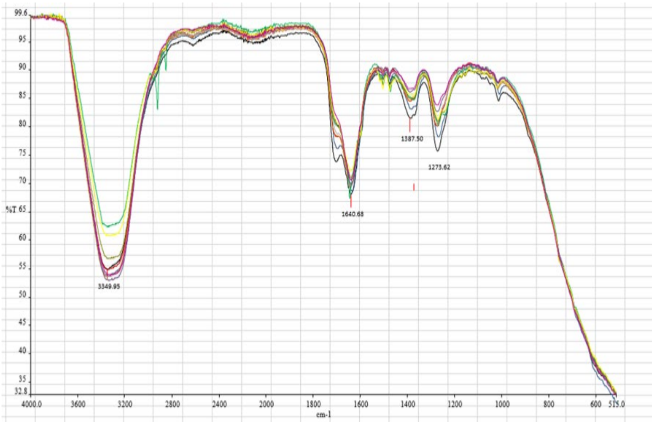

Fig. 6: Overall peak analysis of all 10 fraction of PKS based bio-oil according to their wavelengths.

In conclusion, FTIR analysis detects specific functional groups exist within the PKS and EFB samples. Unlike EFB bio-oil analysis, PKS shows higher margin of deviation due to its temperature sensitive difference but still produce a predictable trend of analysis.

5.4 Chemical Composition Analysis via Gas Chromatography-Mass Spectrometer (GC-MS) Analysis.

For this analysis purpose, only 5 main components are listed depending on their percentage Total Area and their Peak Retention time (min) in ascending order. According to EAG Laboratories (2016), each fraction is identified based on their peak retention time in a period of 1 hour of GC-MS analysis.

5.4.1 *GC-MS Spectra of Empty Fruit Bunch (EFB) Bio-oil*

For EFB bio-oil samples, most of the samples was consist of Acetic Acid group, Amine group, Alcohol group, Furfural group and Phenol group. Amine group such as 5-Amino-3-methylpyrazole and 5-Vinyl-pyrazole shows steady high amount especially in upper fractions of the column, then slowly decreasing going down the column. Acetic Acid group also present in relative high as Benzene, (1,1-dimethylethoxy) from the seventh column until the first column, decreasing from the top to the bottom of the column.

Table 1: The potential compound compositions present in EFB bio-oil fractions using GC-MS equipment.

Fraction	Potential Chemical Compounds	Peak Retention time, min	Total Area, %
10	5-Vinyl-pyrazole	7.411	55.694
	5-Amino-3-methylpyrazole	7.479	8.358
	Benzene, (1,1-dimethylethoxy)	7.580	5.310
	Butanedinitrile	3.335	4.474
	1,3,5-Trioxane	3.484	3.022
9	5-Amino-3-methylpyrazole	7.410	29.330
	Benzene, (1,1-dimethylethoxy)	7.509	23.629
	Furfural	3.654	5.471
	5-Vinyl-pyrazole	4.076	4.760
	Benzyl Alcohol	10.726	4.593
8	5-Amino-3-methylpyrazole	7.484	51.569
	1,3,5-Trioxane	3.677	6.207
	Benzyl Alcohol	10.745	4.557
	Benzene, (1,1-dimethylethoxy)	4.229	4.066
	Mequinol	11.239	2.906
7	Benzene, (1,1-dimethylethoxy)	7.502	49.505
	1,3,5-Trioxane	3.661	5.492
	Benzyl Alcohol	10.744	4.482
	5-Vinyl-pyrazole	4.064	4.145
	Butanedinitrile	3.241	2.549
6	Benzene, (1,1-dimethylethoxy)	7.667	47.054
	5-Amino-3-methylpyrazole	7.557	3.23
	5-Vinyl-pyrazole	4.364	1.65
	Butanedinitrile	3.573	0.795
	Phenol, 2-methyl	9.928	0.669
5	Benzene, (1,1-dimethylethoxy)	7.522	45.827
	Furfural	3.678	5.170
	Benzyl Alcohol	10.748	4.071
	5-Vinyl-pyrazole	4.222	3.721
	Benzene, (1,1-dimethylethoxy)	7.692	3.489
4	Benzene, (1,1-dimethylethoxy)	7.489	47.877
	5-Vinyl-pyrazole	4.063	4.606
	Benzyl Alcohol	10.75	3.929
	2-Pyrrolidinone	5.862	2.606
	1,3,5-Trioxane	3.662	2.553
3	Benzene, (1,1-dimethylethoxy)	7.674	21.852
	Phenol, 4-ethyl-2-methoxy	18.811	4.158
	5-Amino-3-methylpyrazole	7.955	3.918
	Phenol, 2-methyl	8.807	3.476
	2-Pyrrolidinone	6.118	3.437
2	Benzene, (1,1-dimethylethoxy)	7.497	35.1
	5-Vinyl-pyrazole	7.647	5.986
	Nitrous acid, cyclohexyl ester	8.474	4.195
	2-Pyrrolidinone	5.902	4.016
	5-Vinyl-pyrazole	4.060	3.369
1	Benzene, (1,1-dimethylethoxy)	7.674	21.399
	Phenol, 2,6-dimethoxy	18.811	4.072
	5-Amino-3-methylpyrazole	7.955	3.837
	Nitrous acid, cyclohexyl ester	8.807	3.404
	2-Pyrrolidinone	6.118	3.366

Alcohol group such as Benzyl Alcohol and Phenol group (Phenol, 2,6-dimethoxy, Phenol, 4-ethyl-2-methoxy and Phenol, 2-methyl) shows mild quantity in the middle fraction to the bottom fraction of the column. This is because in lower fractions, the amount of phenols is most abundant due to its high polarity and boiling point. Traces of furfural group can be seen in the fifth and ninth fraction due to holo-cellulose decomposition of EFB feedstock during pyrolysis process (Sembiring, et al., 2015).

5.4.2 *GC-MS Spectra of Palm Kernel Shell (PKS) Bio-oil*

For PKS bio-oil samples, the Amine group (5-Vinyl-pyrazole, Butan-2-one, 3-(2-ethynyl)(isopropyl)amino and 5-Amino-3-methylpyrazole) shows high amount such as that in EFB bio-oil samples that is slowly declining from top fraction to the lower fraction. On the other hand, Acetic Acid (Benzene, (1,1-dimethylethoxy), Pyridine, 3-methoxy, Nitrous acid, and cyclohexyl ester derivatives) are actively presented throughout the fractions. Traces of formaldehyde group (1,3,5-Trioxane), Furfural group (Furfural), Alcohol group (Benzyl Alcohol) can also be seen in the GC-MS analysis.

Table 2: The potential compound compositions present in PKS bio-oil fractions using GC-MS equipment.

Fraction	Potential Chemical Compounds	Peak Retention time, min	Total Area, %
10	5-Vinyl-pyrazole	7.622	44.605
	5-Amino-3-methylpyrazole	7.795	17.208
	1,3,5-Trioxane	3.676	7.429
	Butan-2-one, 3-(2-ethynyl)(isopropyl)amino	3.335	4.121
	Benzyl Alcohol	10.798	3.088
9	Benzene, (1,1-dimethylethoxy)	7.596	46.249
	5-Amino-3-methylpyrazole	7.773	19.873
	Nitrous acid, cyclohexyl ester	3.693	7.408
	Butan-2-one, 3-(2-ethynyl)(isopropyl)amino	11.287	4.108
	Benzyl Alcohol	10.789	2.861
8	5-Amino-3-methylpyrazole	7.613	44.437
	Benzene, (1,1-dimethylethoxy)	7.838	21.820
	Butanedinitrile	3.693	6.541
	Butan-2-one, 3-(2-ethynyl)(isopropyl)amino	11.295	3.830
	1,2,5-Trimethylpyrrole	9.945	2.554
7	5-Amino-3-methylpyrazole	7.532	41.907
	Benzene, (1,1-dimethylethoxy)	7.755	25.815

	Furfural	3.662	6.320
	Mequinol	11.253	3.796
	1,3,5-Trioxane	3.412	2.952
6	5-Vinyl-pyrazole	7.544	36.776
	5-Amino-3-methylpyrazole	7.819	30.845
	Nitrous acid, cyclohexyl ester	3.673	5.372
	Butan-2-one, 3-(2-ethynyl)(isopropyl)amino	11.261	3.361
	Butanedinitrile	3.444	3.158
5	5-Vinyl-pyrazole	7.516	34.343
	5-Amino-3-methylpyrazole	7.800	33.460
	Nitrous acid, cyclohexyl ester	3.672	4.952
	1,3,5-Trioxane	3.387	3.483
	1-Hydroxy-4-isopropyl-2,2,5,5-tetramethyl-3-imidazoline	11.254	3.169
4	5-Amino-3-methylpyrazole	7.590	35.623
	5-Vinyl-pyrazole	7.876	30.793
	Furfural	3.700	4.298
	Butanedinitrile	3.452	3.471
	Butan-2-one, 3-(2-ethynyl)(isopropyl)amino	11.289	2.949
3	5-Amino-3-methylpyrazole	7.841	31.281
	5-Vinyl-pyrazole	7.499	27.328
	Benzene, (1,1-dimethylethoxy)	7.708	9.059
	1,3,5-Trioxane	3.669	3.790
	Butanedinitrile	3.354	3.681
2	5-Vinyl-pyrazole	7.701	25.598
	Benzene, (1,1-dimethylethoxy)	8.022	18.655
	Pyridine, 3-methoxy	8.182	16.519
	Dextroamphetamine	3.145	5.601
	Butanedinitrile	3.836	3.490
1	Benzene, (1,1-dimethylethoxy)	7.952	22.170
	Piperidine, 2-(tetrahydro-2-furanyl)	8.133	17.998
	5-Vinyl-pyrazole	7.606	15.593
	Butanedinitrile	3.633	6.263
	Pyridine, 2,5-dimethyl	7.477	6.212

In conclusion, both EFB and PKS bio-oil samples shows relatively significant amount of Acetic Acid. High amount of Acetic Acid groups can retard the high quality of upgraded bio-oil as potential transportation fuels where corrosion is a main concern during application.

6 CONCLUSION

Fast Pyrolysis is used to produce crude bio-oil using PKS and EFB feedstock before being fractionated distillation to further upgrade the bio-oil into 10 fractions each. To determine the characteristic of the upgraded bio-oil for both PKS and EFB, further analysis is being carried out namely physical and chemical analysis. Physical analysis is being done whereby the water content in both samples is recorded and EFB has higher percentage of water compared to PKS bio-oil samples. The pH values of PKS and EFB also shows signs of acidity behavior, due to low pH values. Chemical analysis is subsequently done whereby the functional group of the bio-oil (PKS and EFB) is identified using Fourier Transform Infrared (FTIR) and chemical composition analysis using Gas Chromatography-Mass Spectrometer (GC-MS) method. FTIR analysis shows the functional group behavior with PKS shows higher margin of deviation due to its temperature sensitive difference compared to EFB bio-oils.

Hence, the upgraded bio-oil produced through fractional distillation process is successfully done and most of the quality bio-oil can be collected at the upper fractions of the column in both PKS and EFB bio-oils. But there are also some disadvantages of distillation process for crude bio-oil treatment whereby the acidity and water content of both PKS and EFB bio-oils is relatively high. This may retard the quality of bio-oil as it will reduce its volatility (due to higher water content) and increase potential of corrosion effects (due to high acidity).

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