Pyrolysis of Palm pressed fibre (PPF) Towards Maximizing Bio-oil Yield in a Fixed-bed reactor

K.Azduwin[1, a*], M.J.M. Ridzuan[2, b], A.R.Mohamed[1, c], S.M. Hafis [2, d]

[1]Department of Chemical Engineering Technology, Faculty of Engineering Technology, University Malaysia Perlis, 02600 Pauh Putra, Perlis, Malaysia
[2]Mechanical Engineering Programme, School of Mechatronics Engineering, Universiti Malaysia Perlis 02600 Pauh Putra,Perlis, Malaysia

[a]azduwin@unimap.edu.my*, [b]ridzuanjamir@unimap.edu.my, [c]alina@unimap.edu.my [d]hafissulaiman@unimap.edu.my,

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Abstract. Increasing demand of fossils fuel for many purposes has cause for the limited sources which lead to the finding for new alternative energy based on biomass because of its sustainable properties. Palm-pressed fibre (PPF) is the biomass waste from palm oil processing which has use minimally for boiler to generate heat. The pyrolysis of PPF in a fixed-bed reactor has the potential as an alternative for its conversion into bio-oil, bio-char and gas. The characterization of PPF where involves elemental analysis, proximate analysis, calorific analysis and component analysis. The pyrolysis of the PPF was performed in the fixed-bed reactor at temperature between 300 - 700 °C and heating rate in the range of 10- 70 °C/min with constant flow of nitrogen at 100 cm^3/min and 30 minutes hold time.The highest bio-oil yield produced was 44.98% at optimum temperature 500°C and heating rate 30°C/min. By analysis the bio-oil using Fourier transform infrared spectroscopy (FTIR), it was found to contains alkenes, ketones, polymeric hydroxyl compound, carboxylic acid, aldehyde and water.

Introduction

Malaysia is a country with abundance of biomass creates from agriculture and tropical forest which hold big potential to be use as renewable energy [1]. One of the primary agricultural industries in Malaysia is palm oil industry which produced Palm-pressed fibre (PPF) as the by-product that can be use as the biomass in pyrolysis.

Pyrolysis of biomass is a technique that produces solid (char), liquid (bio-oil) and gaseous products that can be use as alternative source of energy. The pyrolysis process parameters and composition of the feedstock can be adjusted to increase the yield of bio-oil [2].

The pyrolysis of PPF in a fixed-bed reactor is known as an alternative for its conversion into bio-oil, bio-char and gas. However, the pyrolysis of PPF in the fixed bed reactor was less known compare to the other reactor. So that, this study has comes out to identify the effect of pyrolysis process parameters such as pyrolysis temperature and heating rate on the pyrolsis of PPF using a fixed bed reactor.

Methodology

Sample Preparation and Characterization of PPF

The PPF was collected from North Star Palm Oil mills at Kuala Ketil, Kedah Malaysia. The sample was dried before it was ground and sieved to obtain different size in the range of 125µm-2000µm. The characterization of PPF was done to determine the physical and chemical properties of the PPF by undergoes elemental analysis using the Perkin Elmer Series 11 CHNS/O Analyzer 2400, while proximate analysis was done using Perkin-Elmer thermogravimetric analyzer (TGA) and component analysis based on experimental procedure [3].

Pyrolysis Experiment

Fig 1 shows the pyrolysis apparatus set-up. The pyrolysis of the PPF was done in the fixed-bed reactor which consist of a gas cylinder (nitrogen gas, N_2), thermocouple, condenser equipped with cooling circulation unit and controller system. The controller was used to control the reactor system and parameter such as temperature, heating rate and holding time.

Approximately 10 g of treated PPF was fed into the reactor tube. The nitrogen flow rate was fixed at 100 cm^3/min using the flow meter and act as sweeping gas for the fixed bed reactor. Nitrogen was purge at 100 cm^3/min and 30 min holding time constantly for each experiment. The product from the reactor tube were channelled to the condenser and the vapour will be condensed and quench in the condenser before being collected in flask surrounded by ice bath to cool down the condense oil. The uncondensed vapour produce was released out of the system while bio-char was taken out from the reactor tube and weighted at the end of the experiment. The bio-oil that attach to the condenser wall was washed using acetone before being evaporate using rotary evaporator at 62 °C. The attached bio-oil recovered by acetone was mix with the bio-oil collected in the flask as overall mass of oil.

Two process parameter was studied are pyrolysis temperature and the heating rate. The pyrolysis temperatures were varied at 300, 400, 500, 600 and 700 °C. The heating rate used was varied at 10, 20, 30, 50 and 70 °C/min. The optimum yield of bio-oil will be analyzed by using pH meter and FTIR in order to determine the properties of the bio-oil produced.

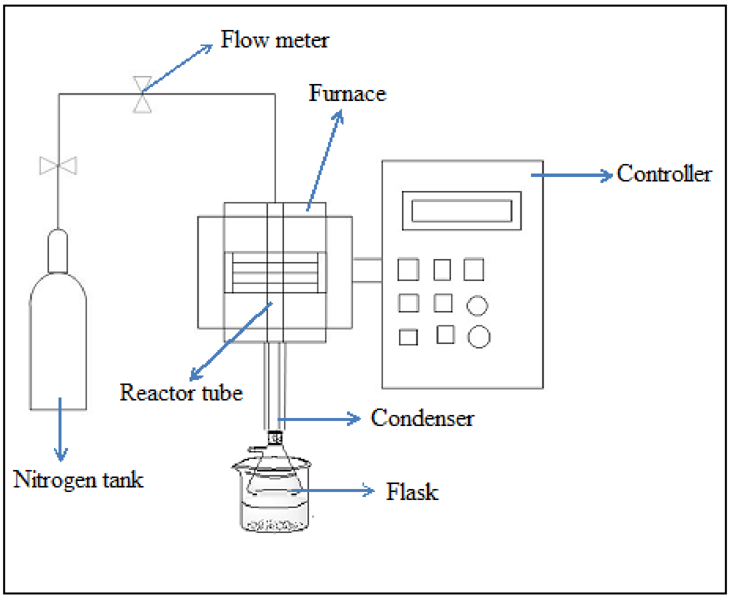

Figure 1: Pyrolysis apparatus set-up

Results and discussion

Characterization of PPF

PPF characterization was done to determine the properties of the PPF and Table 1 represent the results obtained.

Pyrolysis of PPF

Fig. 2 shows the effect of pyrolysis temperature on the yield for bio-oil, bio-char and gas. The gas yield show increase in yield when the pyrolysis temperature increase. The bio-char yield show different pattern as the yield decreased when the pyrolysis temperature increase from 300 °C to 700 °C. The bio-char yield was decreasing when the yield of gas increase. The bio-oil yield was observed to be increase from 300 °C to 500 °C and then decreased with increasing of pyrolysis temperature from 500 °C to 700 °C.The highest bio-oil yield was 44.98 wt % at 500 °C. The increased of the bio-oil yield with the increasing of pyrolysis temperature was because of the decomposition of volatiles content in the PPF which results in production of heavy tars [4]. The bio-oil yield decreased from 500 to 700 °C because of the thermal cracking and catalytic cracking of tar were enhanced when the pyrolysis temperature was high [5].

Table 1 : Characterization of PPF

Analysis	Result
Elemental analysis (wt.%)	
Carbon	32.28
Hydrogen	7.15
Nitrogen	20.46
Sulphur	1.00
Oxygen (by difference)	39.11
Proximate analysis (wt.%)	
Moisture	8.49
Volatiles	77.63
Ash	2.20
Fixed Carbon	11.69
Component analysis (wt.%)	
Cellulose	27.84
Hemicellulose	51.96
Lignin	10.92
Extractive (By difference)	9.29
Calorific value (MJ/kg)	17.818

Fig. 3 shows the distribution of products yields for pyrolysis of PPF at various heating rates from 10 to 50 °C/min. The bio-oil yield increased when the heating rate used were increase from 10 to 30 °C/min.

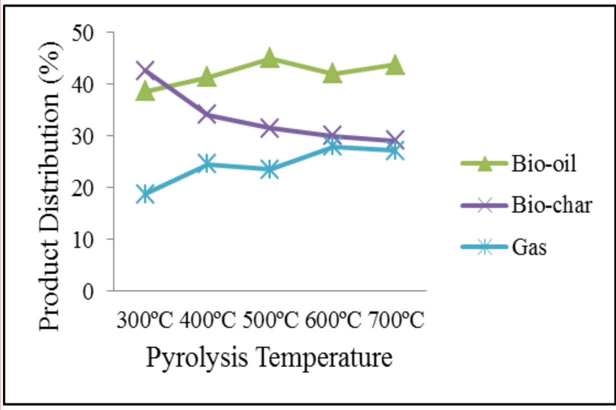

Figure 2 : The effect of pyrolysis temperature on product distribution.

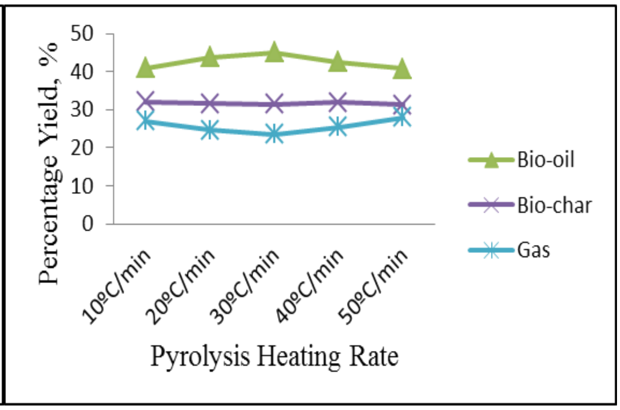

Figure 3 : The effect of pyrolysis heating rate on product distribution

The bio-oil yield then decrease with the increase of the pyrolysis of heating rate from 30 to 50 °C/min. The highest bio-oil yield of 44.98 % was obtained at pyrolysis heating rate of 30 °C/min. The increase in bio-oil yield with the increase of heating rate was because of the resistances made up of strength of mass and heat transfer inside the biomass particle was overcome thus facilitate higher conversion rate of bio-oil yield [6].

FTIR Analysis on Bio-oil

The bio-oil obtain was analysed using FTIR to determine the qualitative impression of the basic functional groups present in the bio-oil. Table 2 simplified the evalution for the absorbance of sample which found to consists of water impurities with polymeric hydroxyl compounds, carboxylic acid, ketones, alcohol, aldehydes and alkenes .

Table 2: Presence of functional groups in the bio-oil produced.

Absorbance (cm^{-1})	Group	Class of compound
3390.3	Hydrogen bonded	Alcohol, phenols
1708.3	C=0 stretching	Aldehydes, carboxylic acids, ketones
1822.4	O-H stretching	Water, ketones, carboxylic acid, alcohols
1495.0	C=C	Alkenes
1275.8	C-H	Alkanes
1143.6	O-H	Aromatic groups

Conclusion

By the overall work, the conducted experiment on pyrolysis temperature and heating rate give the best result of 500°C and 30°C/min with the bio-oil produced at this condition is 44.98%. The bio-oil yield decreased when temperature was above 500°C because of the thermal cracking and catalytic cracking of tar were enhanced when the pyrolysis temperature was high while the higher heating rate improve the yield of bio-oil as the fragmentation rate of biomass increased thus improve the yield of volatile. Bio-oil produced was found to contain functional group such as alkenes, ketones, polymeric hydroxyl compound, carboxylic acid, aldehyde and water.

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