

DESIGN AND IMPLEMENTAION OF A LABORATORY-SCALE PYROLYSIS COMBUSTOR FOR BIOMASS CONVERSION

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ABSTRACT: A semi-auto pyrolysis system was fabricated and experimental results on fast pyrolysis of biomass residues; empty fruit bunch (EFB) process was investigated. The vertical fluidized bed reactor with the dimensions of 1000mm length and diameter ID 25mm was used in carrying out the pyrolysis experiments. Three main products were obtained from the fast pyrolysis were bio-oil, bio-char and non-condensable gases. The particle size was used $100\mu\text{m} \pm 5\%$. The effects of the pyrolysis temperatures were investigated. Under the 500°C, the maximum bio-oil yield obtained was 52.79 wt %, the optimum bio-char yield was 35.11 wt% at the temperature of 450°C and the highest yield of bio-gas was 58.88 wt% at the temperature of 600°C. Furthermore, bio-oil analysis was conducted based on the American Society Testing and Material (ASTM) methods. The pH value obtained was in the range of 2.20 to 2.74, the pour point of the bio-oil was -11°C, the cloud point was -9°C, the density was 1054.92 kgm⁻³ and the kinematic viscosity of the bio-oil was 1.61mm²s⁻¹.

Keywords: Empty Fruit Bunches (EFB), Fast pyrolysis, Bio-oil, Biochar.

1. INTRODUCTION

A process of thermal conversion in the absence of oxygen can be used to transform biomass into different useful products such as bio-oil, char and biogases. The biomass is from the agricultural wastes renewable resource such as rice straw [1], wheat straw, corn straw [2], Empty Fruit Bunches (EFB) [3-4], rice straw, bamboo sawdust [5] and others. A significant effort has been made to produce the biofuels from bio-oil production [6]. The fast pyrolysis is able to produce the yield of bio-oil up to 75 wt% if compared with other methods [7]. World conventional petroleum oil supply is at political risk [8] because this is due to petroleum mainly from Middle-East suppliers. Thus, unexpected new technology increases in the production of petroleum oil and gas of 30 percent in United State of American (USA) [9]. Malaysia produced a lot of palm oil and an abundance of EFB, front, shell, trunk and Palm Oil Mill Effluent (POME) [10]. This abundance of palm oil showed the significant of environmental pollution. The proper treatment should be applied to the waste of palm oil such as pyrolysis process. Biomass is a clean, commercial, carbon neutral renewable feedstock that consists of low nitrogen and sulphur contents which is useful as the raw materials for the production of bio-fuel.

The slow pyrolysis is primarily used for the production of bio-char. In the slow pyrolysis, the vapor residence time used was too high which was 5 minutes to 30 minutes and caused the vapor phase components to continue reacting with one another to form solid char and other liquids. The long vapor residence time required extra energy input. As the high residence time caused the primary cracking, the quantity and quality of the bio-oil yield are affected. [12]

The fast pyrolysis is a process which uses high temperature to heat the biomass without the presence of oxygen, vaporizes and condenses into a dark brown liquid known as the bio-oil. This liquid contains about half of the heating value of the conventional fuel oil. The fast pyrolysis benefits in a way that it can produce the liquid fuel directly. The fast pyrolysis can be done with or without the use of catalyst. The non-catalytic fast pyrolysis is the thermal cracking process which is widely

used in producing the bio-oil as it increases the bio-oil yield and decreases the bio-char yield. The fast pyrolysis process requires a very high heating and heat transfer rate, a very fine grounded biomass, a controlled temperature, which is around 450°C -600°C and a speedy cooling process for the vapors to produce bio-oil. [13].

The flash pyrolysis is a rapid devolatilization process in an inert atmosphere which uses the high heating rate of biomass particles, high reaction temperature from 450°C to 1000 °C but low residence time (<1 second). This pyrolysis can produce bio-oil up to 75%, but has limitations such as poor thermal stability and corrosiveness of the oil [12]. The decomposition of biomass into liquid fuel, gaseous and solid has to go through the thermal heating process without the oxygen environment. Few grams of biomass are inserted into the reactor tube. When the temperature is reached to the require reading, reactor tube can be inserted into the furnace for pyrolysis process. The nitrogen gas has to be supplied into the reactor all the time during the pyrolysis. Condensable volatiles are collected using the cold water and tube glasses. Fig. 1 shows the flow diagram of the pyrolysis chemical process.

2. METHODOLOGY

Pyrolysis of various kinds of biomass can be done by using many different choices of reactors such as fixed-bed reactors, fluidized-bed reactors, free-fall reactors, rotating cone reactors, auger reactors, ablative reactors and others [14]. Fluidized-bed and fixed bed are the main reactors used for the design of pyrolysis vertical combustor for biomass conversion process. This design is implemented pyrolysis reactor tube with upward or downward nitrogen gas flow. The concept design of pyrolysis system is based on the pyrolysis chemical process as well as to verify the efficiency and functionality of this new rapid automated pyrolysis machine. The chemical process is to convert any biomass to bio-oil, bio-char and biogas. The manually basic pyrolysis setup could use with nitrogen gas, tubular furnace and glass reactor. This setup had the safety issues [15] because hand on operation was needed manually

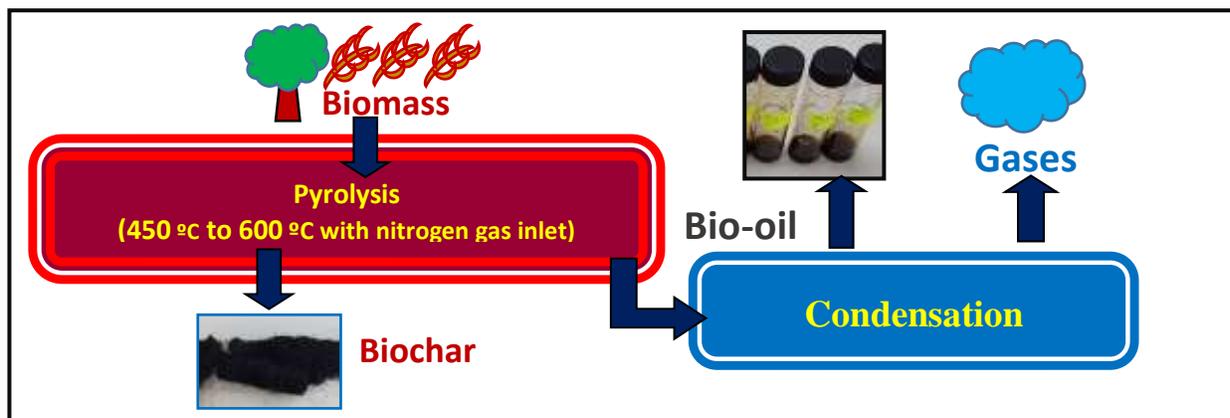


Fig (1) Block diagram of the pyrolysis process

to adjust the reactor when the heater was heated up to 500 °C. The pyrolysis was performed under the nitrogen flow rate of 0.6 L/min at the atmospheric pressure. The heating rate of the controller is at 100 °C/min. The pyrolysis experiment is held for 10 minutes until that was no significant gas was observed. The particle size of biomass in this experiment was 100µm ±5% which was according to the potential automation design of pyrolysis vertical combustor for biomass conversion [16]. The semi-auto rapid prototype pyrolysis was fabricated for the low cost and university research purpose. Fig. 2 shows the schematic diagram of the pyrolysis of biomass.

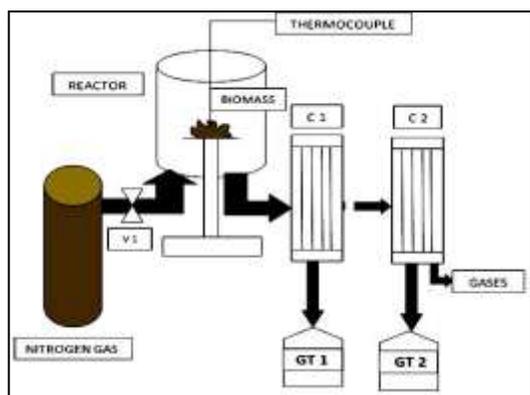


Fig (2) A schematic diagram for the pyrolysis of biomass. (V1) Nitrogen gas flow control; (C1) Condenser 1; (C2) Condenser 2; (GT1) Glass tube 1; (GT2) Glass tube 2.

3. Hardware Fabrication

Fig. 3 shows the fabricated pyrolysis system. Based on the design, the condensers setup in Fig. 3 (d) was used flasks but there were not able to condense the bio-oil after 3 consecutive experiments were carried out. However, the biochar is able produced along the process. Thus, the flasks were changed to the test tubes as a condenser to overcome the design which was according to Bridgwater AV [13], the condensers set up.

4. MATERIALS AND METHODS

Fig. 4 shows the flow diagram process to convert the biomass into bio-oil. The EFB were collected and dried under the sun for 24 hours before undergoing the second

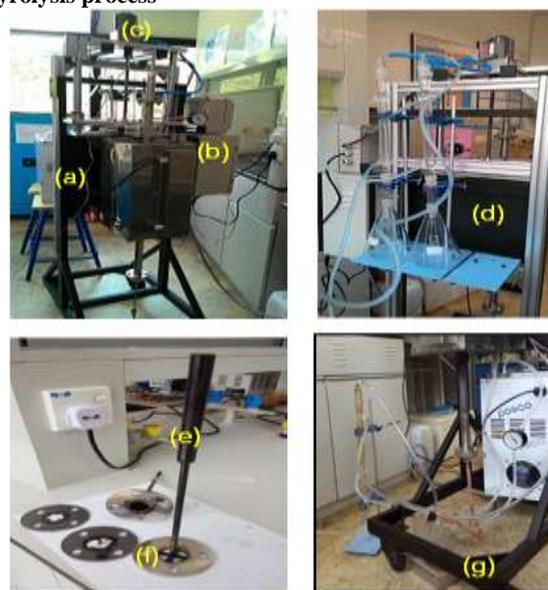
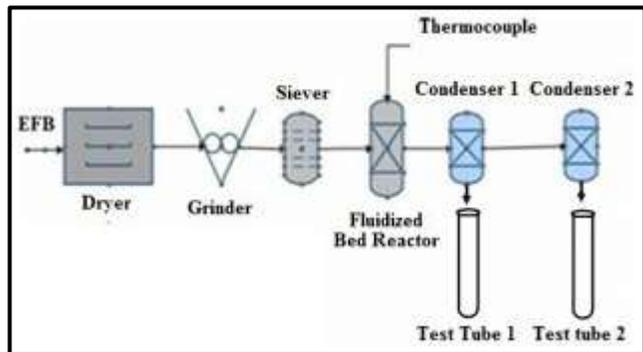


Fig (3) Vertical fluidized-bed pyrolysis system. (a) Front view of pyrolysis system; (b) Temperature control system and motor control; (c) Motor pull up/down for reactor (d) Rear view of condensers system; (e) Feedstock holder; (f) Reactor cylinder flange; (g) Modification structure of condensers.

drying process in the oven at the temperature of 105°C for another 24 hours. The dried biomass was then crushed, sieved and separated into smaller fractions by using a sieve shaker (SIEVE-TRONIC). The pulverized biomass (100 microns meter) were weighed and introduced into the reactor. The nitrogen gas, N₂, which acts as the fluidizing gas was also introduced into the reactor. The EFB was weighed before and after the process run. The difference in weight of the biomass was the weight of the bio-char. The gases which exit the reactor were passed on to the condensers to allow condensation to occur and produced bio-oil. The bio-oil was collected in the storage tank prepared and weighed. The total yields weight of the bio-oil, bio-char and combustible gas can be defined as following equations:

$$\text{Bio-Char Yield (\%)} = \left[\frac{\text{Weight product (char) (g)}}{\text{Weight of Biomass feed(g)}} \right] \times 100\%$$



Fig(4) Flow diagram process of biomass to bio-oil conversion

$$\text{Bio-oil Yield}(\%) = \frac{\text{Weight of Bio-oil product (g)}}{\text{Weight of Biomass feed(g)}} \times 100\%$$

$$\text{Gas Yield} (\%) = 100\% - (\text{Char Yield} + \text{Bio - oil Yield}) .$$

5. RESULTS AND DISCUSSION

Table 1 shows the result of bio-oil, bio-char and non-condensable gases obtained from the experiment at the different temperature. From the fast pyrolysis experiment, the maximum bio-oil yield obtained was 52.79 wt % of the temperature at 500°C, the optimum bio-char yield was 35.11 wt% at the temperature of 450°C and the highest yield of bio-gases were 58.88 wt% of the temperature at 600°C. Fig. 5. shows the graph of product yields vs temperature which plotted based on the result obtained from the experiment. The results were shown a similar graph if compare from Zhiqian Hu [16]. As shown in Fig. 5., the maximum bio-oil yield obtained was 52.79 wt% of the temperature at 500 °C, the optimum bio-char yield was 35.11 wt% at the temperature of 450°C and the highest yield of bio-gases was 58.88 wt% of the temperature at 600 °C. Table 2 shows the general characteristics of Bio-oil results obtained from the experiment. Bio-oil analysis was conducted based on the American Society Testing and Material (ASTM) methods.

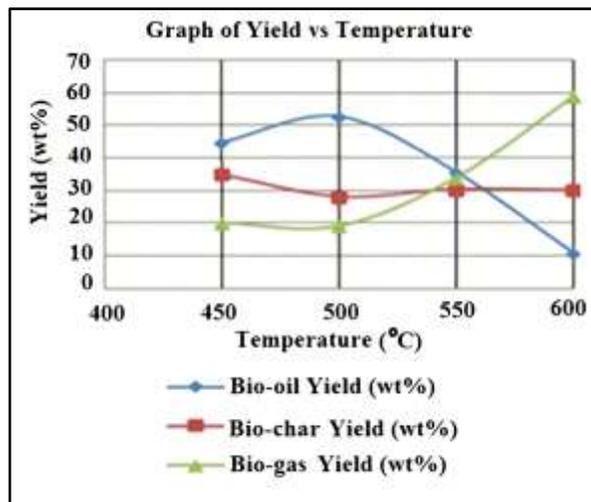
Table 1: Results of Bio-oil, Bio-char and Non condensable Gases

Temperature(°C)	Yield (wt%)		
	Bio-oil	Bio-char	Biogas
450	44.68	35.11	20.21
500	52.79	28.05	19.16
550	35.68	30.42	33.9
600	11.01	30.11	58.88

Table 2 General Characteristics of Bio-oil

No	Characteristics	Result	ASTM Method	Apparatus
1.	Pour Point	-11°C	ASTM D97	Test Jar, Thermometer, Cork, Jacket, Disk, Gasket, Bath, Acetone
2.	Cloud Point	-9 °C	ASTM D97	
3.	Kinematic Viscosity@ 40°C	1.61mm ² s ⁻¹	ASTM D445	Canon-Tenske Routine
4.	Density	1054.9kgm ⁻³	ASTM D4052	Picnometer
5.	pH	2.20-2.74	pH meter	pH 700(EUTECH)

The pH obtained was in the range of 2.20 to 2.74, the pour point of the bio-oil is -11 °C and the cloud point was -9 °C based on ASTM D97. The density calculated was 1054.92kgm⁻³ according to ASTM D4052. The kinematic viscosity of the bio- oil was found 1.61mm²s⁻¹ by using the ASTM D445. The pour point temperature was at -11°C. The pour point temperature was a good temperature as it showed that the bio-oil requires lower temperature for it to lose its characteristic of flow and represented the temperature for the oil to be pumped.



(5) Graph of Product Yields vs Temperature

In pyrolysis, low pour point is a good indication for the low viscosity if compared with Oasmaa & Peacocke [17]. On the other hand, the cloud point obtained was at -9°C. The pH of the bio-oil represented the corrosiveness of the oil but did not play the role of concentration of acidity. The pH and density obtained from this experiment ranged from 2.20 to 2.75 and 1054.9 kgm⁻³ where according to Lehto, *et al* [18], the pH and density of the bio-oil from the untreated biomass was in the range of 2.5 to 3.0 and 1100 kgm⁻³ to 1300 kgm⁻³. A study on the silica gel from Oil Palm Boiler Ash [19] had gone through the microwave combustion temperature range of 500°C to 900°C within oxygen environment. The microwave combustion can replace by this new pyrolysis system to synthesis the silica gel. The characteristic of the silica gel results can also be compared with these microwave and furnace

6. CONCLUSION

This pyrolysis system had been designed and fabricated which can be used to produce the bio-oil, bio-char and non-condensable gases, simultaneously. And from the result obtained from this design had been compared with the standard range of the bio-oil and bio-char which scientifically proved that the result obtained are in the correct properties. To obtain the highest bio-char, temperature should be below 400°C. To obtain the highest bio-oil, temperature should be at 500 °C while to obtain highest gases, temperature should be above 550 °C.

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