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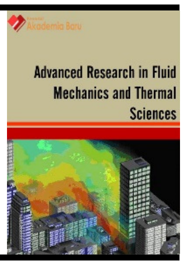

Catalytic fast-pyrolysis process design and equipment setup for converting palm oil empty fruit bunch biomass to bio-oil

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ABSTRACT

Fast-Pyrolysis is a well-known technology for breaking down molecular composition of organic materials into gas and liquid forms by mean of high temperature treatment in the absence of oxygen. Reactors accommodating this means of transformation has been variously designed and implemented in bench-scale as well as pilot and commercial scales. In this paper, we will discuss on the process design that fulfilled the catalytic fast-pyrolysis method as well as the equipment setup to realize this process of a pilot scale production. The design is to realize targeted heating process temperature to maintain at 320 °C, mix material with specified catalyst while occupying a 20 feet size container unit for space optimization. A shredder, industrial mixer, reactor and condenser are placed adjacently in the unit. Prior production test ran achieved desired temperature of both reactor and condenser.

1. Introduction

Empty Fruit Bunch (EFB), a solid residue which accounts for 20% of the fresh fruit weight, is one of the palm biomass produced in abundance about 4.42 ton hectare yearly [1] after oil extraction at palm oil mills. In the past, EFB was used as fuel to generate steam by incineration at the mills and the ash produced was used as fertilizer or soil conditioner [2]. However, incineration of EFB was soon discouraged due to the emission of a large amount of white smoke mainly down to its high moisture content >60% of total EFB weight. Even though not harmful to health, the white smoke had a significant aesthetic impact on the surrounding environment.

Today, EFB is largely used as organic mulch in plantation as a substrate for mushroom cultivation or left to rot and returned to the fields a complementary fertilizer. While these practices could mitigate the need for EFB disposal, there is still plenty of EFB available that can be used for more

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lucrative purposes, for instance to produce biofuels and/or green jet-fuel to satisfy for the nation's aviation industry.

Traditional methods of composting and incineration process for this organic solid wastes also releases nitrogen, considerable amount of solid grains and smoke to the environment [3].

Pyrolysis process is one of the most suitable technologies of biomass utilization which converts the biomass to bio-oil, char and gases depending on the pyrolysis conditions. It is hypothesized that production of biofuel from biomass could be achieved with higher efficiency and enhanced production yields. However, pyrolysis process usually requires high temperature. Despite of inefficient of power and time consumption, according to Chang et al.[4] pyrolysis process at high temperature produces higher amount of H2 and CO gas, which does not condense, hence producing less oil yield. Therefore, fast pyrolysis at lower degradation temperatures (300–375 ºC), in the presence of functionalized nano catalysts is an efficient one step conversion of biomass to biofuels conversion with optimum yield.

The objectives of this paper is to discuss on the process design to transform EFB biomass into gas and liquid phase with lower temperature than normal pyrolysis as a result of nano catalyst involvement and the equipment setup installation of a pilot-scale reactor plant. The production should reflect the result of about 60% yield obtained in the bench-scale tests done prior to the installation. The pilot-scale reactor is expected to run at maximum of 10 kg EFB, 20 times more than in the bench-scale experiment and will be a benchmark for a larger capacity benchmark up to commercial-scale later on in the future.

2. Material and Methods

2.1 Raw Material

EFB raw material for the conversion process was collected from the palm oil plantation in Bagan Datuk, Perak. After the fresh fruit were collected at the factory, EFB was conveyed and chopped in the way to the accumulation centre at the open outside area. These abundance of EFB were left for some time under the sun and whilst, nature taking place of degradation. Portion of the towering collection was transferred and treated with decomposing bacteria undergoing a proper fertilization process. This time consuming process of one and a half month could not cope with the amount of supplied EFB wastes. Thus, this becomes opportunity for research in varying the reuse of the biomass. Upon collected, EFB needs to be washed by tap water in order to remove dirt and ash held onto the bunch. The clean EFB was then sifted and sun-dried. Then, dried EFB was ground into 10-20mm length fibre using a disk mill. This fibrous EFB is weighted for desired amount and considered as ready raw material for the next step of the process. Part of the study is to see the significant of delignification pre-treatment process on EFB towards the efficiency of the bio-oil production.

2.1.1 EFB delignification pre-treatment

Palm Oil Empty Fruit Bunch consists of lignin, cellulose and hemi-cellulose. The pre-treatment of EFB is crucial to remove lignin complicated and strongly linked molecular structure, compared to the other two components. In order to further prepare the EFB raw material as to easily break the structure during pyrolysis process, a pre-treatment better known as delignification is important. This process is done by soaking EFB in NaOH solution [5]. Removal of lignin will reduce the time needed for the decomposition of EFB during pyrolysis process.

The EFB raw material used in this study is collected from Sime Darby Palm Oil Flemminton Plantation in Sg. Sumun, Bagan Datuk, Perak. The partly chopped bunches is then dried openly under the sun to eradicate the remaining water content and further finer grounded using in-house grinder. This is categorized as unwashed EFB in this experiment. While, second set of EFB is soaked into distilled water for 24 hours before being sieved and baked to dry in the oven of 85°C overnight. This sample is categorized as washed EFB. NaOH solution is prepared for soaking.

NaOH concentration of 2.5 M was used in this formulation to soak 20 g of EFB [6].

Table 1
Calculated Amount of NaOH Mass Used in the Experiment

Molarity (M)	Distilled Water	NaOH molar wt.	Mol (n)	NaOH mass
(g/mol.l)	(l)	(mol)	(g/mol)	(g)
2.5	0.15	40	0.375	15

Wash and unwashed EFB were prepared to inspect the efficiency of delignification process comparing the two. To prepare the solution, 0.15 liter of distilled water was added and slowly stirred until it fully dissolved. The EFB is soaked into the solution and left for intended time of 2, 4, 6, 12, 22 and 24 hours. Two sets of EFB samples were prepared; for Unwashed and Washed EFB. End of these hours, the EFB was again sieved and weighted. They were then baked to dry in the oven of 85 °C for at least 3 hours, before being weighted again. The difference between both data taken was proportional to the removal of Lignin composition in EFB which had been extracted into NaOH solution. The trend of these data was monitored and analyzed.

2.2 Catalytic Fast-Pyrolysis

Pyrolysis is a thermochemical decomposition of biomass of high temperature treatment up to 800 °C in the absence of oxygen. The addition of nano catalyst will reduce the required temperature to approximately 320 °C. The decomposition process releases volatile and non-volatile forms. Gas-phase volatile forms condensed into black viscous fluid termed bio-oil [7] that also known as many different terms includes pyrolysis oil, bio crude oil, bio fuel oil, wood liquid, wood oil, liquid smoke, wood distillates, pyroligneous tar, and pyroligneous acids [8]. Parameters that differ and vary pyrolysis into types are resident time, temperature and heating rate. They affected the percentage of gas, char, and fluid products produced. The methods of practising pyrolysis can be categorised into conventional, slow, fast and flash pyrolysis [9] depending to its varying speed of heating.

Catalyst is known to be used to improve reactions in various types of fast-pyrolysis processes. Over the years, many types of metal oxide catalysts were introduced to renewable energy pyrolysis processes such as of CuO, SiO, Ca(OH)2, K2CO3 and MgO [10][11] resulting various views on efficiency towards yielding as well as temperature rating required. While as for temperature of reactor heating, a pyrolysis process without catalyst, Mohamed et al [10] determined that at 500 °C can achieve up to 35 % maximum yield of bio-oil. This is supported by Sembiring et al [12] that concluded that the bio-oil is optimized at 500 °C though yield is lower at 27 %.

As in this process, the catalytic pyrolysis should have reacted under 500 °C and achieve the targeted temperature to be less or constant at 320 °C with the introduction of catalyst within a simple reactor design utilizing concept of transforming matters under heat and rapid cooling. Defined the parameters in need, lower temperature and higher yield, a reaction plant was designed. Figure 1 shows the EFB Biomass to Bio Oil Catalytic Fast-Pyrolysis Process Flow Diagram.

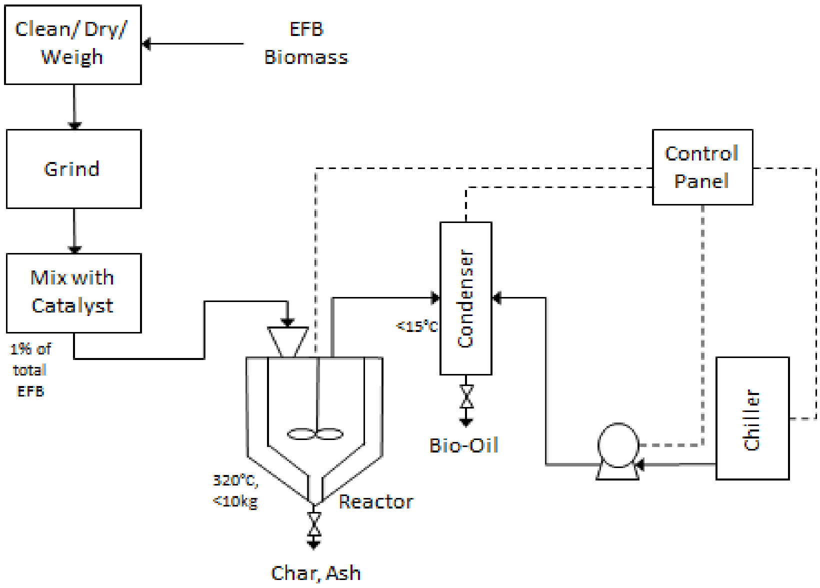

Fig. 1. EFB Biomass to Bio Oil Catalytic Fast-Pyrolysis Process Flow Diagram

Catalyst to be used in the test is zeolite A, prepared using Rice Husk Ash (RHA) and synthesized with SiO, Al(OH)3, NaOH and water. The choosing of finalized catalyst to be used is supported by Zakaria et al [13] that concluded zeolites A and X yielded bio oil of 60 % and 41 %, respectively under bench-scale fast-pyrolysis process of the same reaction reactor's concept. Zeolite A particle size is smaller (70-200 nm) and contains more Na ions compared to zeolite X, which lead to ion exchange in the pyrolysis reaction and eventually contributed to more production of bio-oil yield. Therefore, in this design of pilot-scale size, the expected yield is 60 % using zeolite A as catalyst.

Table 1 shows the amount of EFB and nano catalyst ratio needed per constituted weight as per bench-scale experiment. Thus, reciprocally the pilot-scale process material mixing should reflect 1% of catalyst as EFB amount needed for each batch of EFB tested in the reactor.

Table 2
Formulation of Estimated Mixture of EFB and Nano Catalyst

EFB Input Require				Estimated Catalyst Needed	Estimated Produced Bio-Oil
(gram/min)	(kg/hour)	(kg/day)	(kg/year)	1% of yearly weight (kg)	60% of yearly weight (kg)
200	12	96	19,200	192	11,520
250	15	120	24,000	240	14,400
300	18	144	28,800	288	17,280
350	21	168	33,600	336	20,160
400	24	192	38,400	384	23,040
450	27	216	43,200	432	25,920
500	30	240	48,000	480	28,800

2.3 Equipment Setup

A pilot-scale pyrolysis system is designed to accommodate a maximum of 10 kg EFB per process at a time. Upon mixture of raw material and 100 g catalyst according to calculated ratio, an output of 6 kg bio oil is expected. All equipment are placed adjacently to fit a 20 x 8 x 8 feet mobile container. This system consists of a 415 V main switch breaker with control panel, a shredder unit to grind EFB fibres into intended size at maximum of 23 mm in length per strand, a weighing scale, an industrial mixer, condenser system and a heating reactor.The reactor and condenser are custom-built to reflect and fit the design process flow while the others component and accessories are purchased directly from existing market specification which suit to the needs of the process. Figure 2 shows the design drawing of the reactor and condenser.

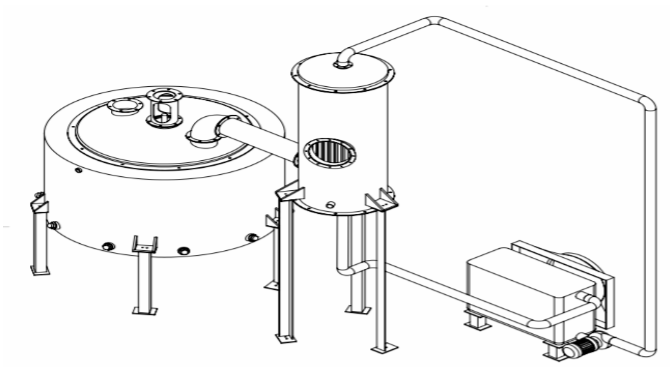

Fig. 2. Design Drawing of EFB Reactor and Condenser

Reactor unit can contained total volume of 300 L is where the catalytic pyrolysis process of empty fruit bunch with specified temperature take place. During the rapid heating process, the mixture molecular bond will transform into char and gases. The material used to build the reactor is stainless steel 304 (SUS 304) due to its high melting point properties that is 1399oC – 1454oC and also has good thermal conductivity that is 16.3 W/m.k. The cover of the reactor is made using the same material with thickness of 3mm. The cover is holding the motor connected to an agitator, a dispenser and tightly closed to prevent gases from entering or escaping the reactor. These gases will be channelled to a condenser through a piping connector.

The heating element coiled inside the reactor casing will maintain specific designated temperature by the supplement of thermo oil which in this design is using the type that has flash points over 400 oC. In Figure 3 below shown the composition of parts on the built reactor unit.

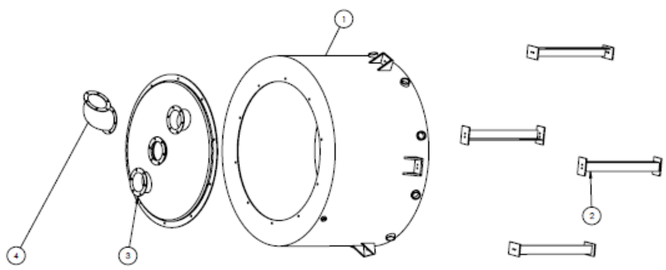

Fig. 3. Composition of Reactor Unit; 1. Reactor container, 2. Bracket, 3. Reactor cover, 4. Reactor piping to condenser

The condenser is built with series of vertical copper tubes filled with chilled water to enable the condensation process that the gases will experience from being heated up to 320 oC in the reactor towards immediate cool of <15 oC. Rapid cooling transforms the gases that are trapped inside the condenser into liquid form. The result is a collective amount of bio oil. The condenser container is also made from the same material as the reactor which is SUS 304 with 3 mm thickness. The bottom portion of the condenser is installed with a valve that allows the flow of the liquid into a glass beaker. The condenser is worked in a loop of inlet and outlet points to continuously provide chilled water during the process.

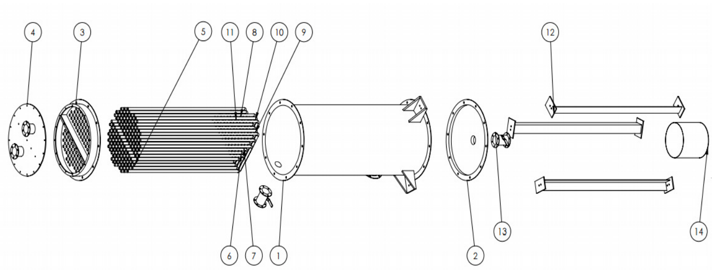

Fig. 4. Composition of Condenser Unit; 1. Condenser container, 2. Condenser bottom cover, 3. Condenser water separator, 4. Condenser top cover, 5-11. Copper tube, 12. Bracket, 13. Valve, 14. Beaker

Other equipment accessorized for the whole system in the container is specified in Table 3 below.

Table 3
Equipment Specification

No	Item	Specification
1	Shredder/Disk mill	2.2-3k/W 30 kg/hour Rated Speed: 5800 rpm Voltage: 240V
2	Weighing Scale	Up to 150 kg Voltage: 240V
3	Universal Mixer	1.1k/W 20L capacity Rated Speed: 104/187/358 rpm Voltage: 240V

3. Result and Discussion
3.1 Material
3.1.1 EFB pre-treament

Result from the experiment shown that lignin removal is directly proportional with time and the maximum lignin removal was 4.7 %. NaOH acted as nucleophiles pulping chemical that react with lignin thus fragmented modified and dissolute the lignin structure in the reaction medium. The lignin structure modification occurred in two steps as to improve its dissolution as first broke the bond of inter-unit linkages of lignin into smaller units. And then, the hydrophilic groups were introduced into it. Resulting of a more soluble and optimum lignin [14] for the process. Washed EFB has shown a better and faster lignin removal rate compared to unwashed. The result is graphically visualised in Figure 5.

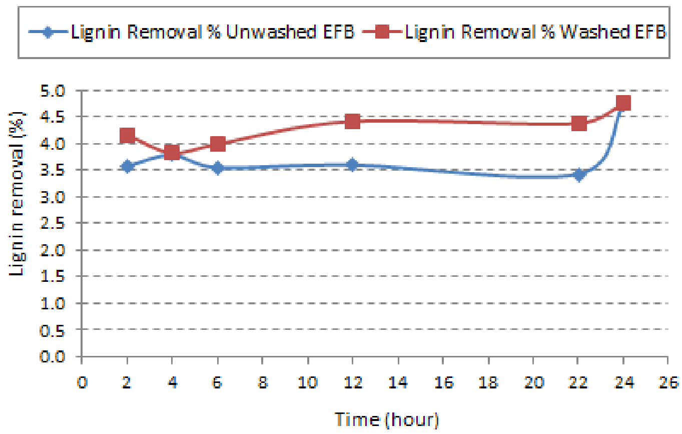

Fig. 5. Lignin Removal Percentage between Unwashed and Washed EFBs

The optimum hour of delignification to be done prior to the pyrolysis process should be at 12 hours as the removal afterward is trending slow and time consuming. Washed and treated EFB shown better yielding of bio-oil. Thus, the process flow should consider these procedures in the whole process design.

3.2 Catalytic Fast-Pyrolysis Reactor

A pilot-scale production plant is designed upon studying the needed parameters and concept realization of matters transformation via heating and cooling. Figure 6 below shown the photo of the actual built of the catalytic fast-pyrolysis system in UTM Kuala Lumpur campus.

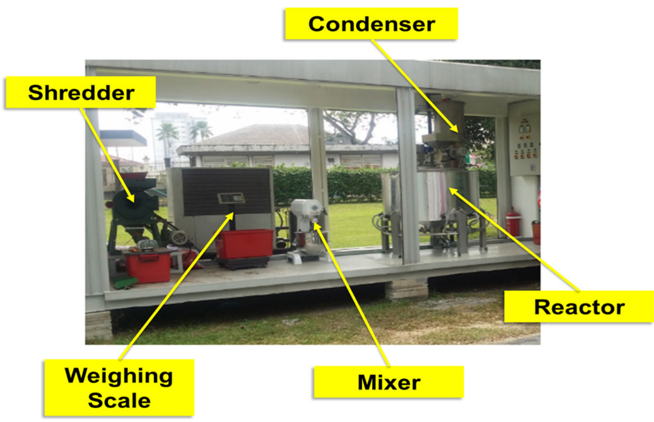

Fig. 6. Container Unit Consist of Equipments located at UTM Kuala Lumpur

4. Conclusion

This paper explained a simple built of a catalytic fast-pyrolysis process system. A concept of heating and rapid cooling is introduced in the system design. Zeolite A as specified catalyst mixed with the biomass raw materials in this study helps to lower the needed temperature for a pyrolysis reaction. Furthermore, a compact yet practical space consumption is well portrayed in this design by accommodating the most out of a 20 feet container. This paper also discussed on the better performance shown by washed EFB portion in the experiment of delignification for pre-treatment as preparation of material towards better pyrolysis process and bio-oil production. Few tests had been undergone and yet to receive the GC-MS material characterization results. The process however, shows promising yield of targeted 60 % bio-oil production upon further optimization.

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