Determination of Parameters for Biochar Production from Biomass Waste using Rocking Kiln - Fluidized Bed System

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***Abstract*— Biomass waste is one of the sources for renewable energy. Biomass energy can be produced from combustion technology, anaerobic digestion and pyrolysis. Combustion technologies are such as rotary kiln, fluidized bed, rocking kiln, bed grate furnace, combustor and others. Biomass was converted to bio char using the developed Rocking Kiln-Fluidized Bed (RK-FB) system. RK-FB is a combination technology of rotary kiln, fluidized bed and rocking kiln for combustion. The objective of this work is to measure the optimum parameters to produce the bio char using the RK-FB. In this work, cold run and hot run were conducted to obtain combustion parameters. From this study, parameters obtained from cold run methods were total air for fluidization, rocking speed and residence time while the hot run method obtained parameters of the suitable temperature, the angle of the system, residence time, total air for fluidization, rocking speed, reduction of weight sample and Calorific value of the bio char produced. The samples used in this research were biomass waste from palm oil kernel shells. From the study, the suitable parameter for this new system to work efficiently were temperature 680°C-720oC, flow rate at 200-300 l/m, angle of the rotary kiln at 7º, residence time at 20- 25 minutes and weight reduction of palm oil kernel shells at 70%. The study also found that charcoal or bio char have calorific value, 33MJ/Kg. It is concluded that the parameters used in this work are suitable the Rocking Kiln – Fluidized Bed for production of bio char from biomass waste.**

Keywords*— *Biomass waste; Incineration; Municipal Solid Waste (MSW); commissioning.

I. INTRODUCTION

Biomass energy sources are produced from materials that are derived from plants where the sources of these plants coming from either land or sea. Biomass includes all the plants specifically for energy resources or waste products from various woods, plants and municipal waste.

The biggest biomass source in Malaysia comes from oil palm industries. According to (Zuhaira et al., 2018) the oil palm industry is one of the main industries in Malaysia that contributes to the country's gross domestic product (GDP). Malaysia had approximately 4.75 million hectares of palm oil under cultivation which covers about 60% of the country's agricultural area (Shafie et al., 2012). Malaysia is the second world`s largest supplier of palm oil after Indonesia (Malaysia Palm Oil Sector, 2012) and has supplied 30% of the world demand on palm oil.

Since Malaysia is the largest production of palm oil, the industry generated vast quantities of palm biomass, mainly from milling and crushing palm oil. According to the Malaysian Palm Oil Industry report (Malaysian Palm Oil Industry, 2014), the types and amount of these biomass generated in 2014 are shown in Table (1).

TABLE 1: PALM OIL BIOMASS GENERATED IN YEAR 2014

Biomass	Quantity (Million Tonnes)	Calorific Value KJ/kg	Moisture Content %
Shell	5.2	20108	12
Fiber	7.69	19068	37

Most biomass can be used as combustion fuels. In the normal practice, the kernel shell and fiber used as main fuels for main sources of energy in palm oil mills. The fuels are burn in the boiler to produce steam for electricity generation for use in the milling process (Nasrin et al., 2008).

Biomass energy production from biomass waste can be from combustion technology, anaerobic digestion and pyrolysis. Combustion technology involves rotary kiln, fluidized bed, rocking kiln, bed grates furnace, combustor and others. Rotary kiln technology includes rotation method and the residence time. The residence time depends on the length and diameter of the rotary kiln and the total stoichiometric air given to the system. Fluidized bed is another technology in combustion while the method uses air and sand. The total air located at bottom of fluidized bed system is one factor to contribute the suitable fluidization in the system.

In this work, the determination of combustion parameters is essential in obtaining the desired bio char. Hence, the objective of this research is to study the performance parameters of the Rocking Kiln – Fluidized Bed (RK – FB) system. The parameters involve in the study include the temperature, the angle of the system, residence time, total air for fluidization, rocking speed and reduction of weight sample.

II. MATERIALS AND METHODS

A. Characterization of the Palm Kernel Shell

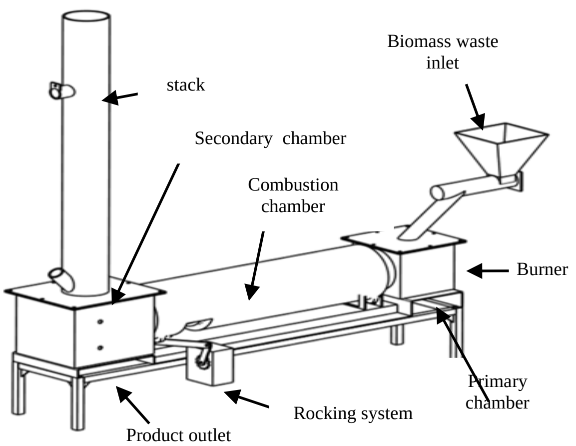
The palm kernel shells were obtained from the oil palm processing plant of Seri Ulu Langat Palm Oil Mill Sdn. Bhd, Dengkil, Selangor. Palm kernel shell characterization conducted using proximate and ultimate analysis. Proximate analysis, determine the energy, humidity, volatile matter, ash and fixed carbon found in biomass raw materials (palm shells) using the standard method described in ASTM-84 (American Society for Testing Materials- 84) while the ultimate analysis determine the content of carbon, hydrogen, oxygen, nitrogen, sulfur and ash according to weight percentage basis.

B. Experimental Rig for Biochar Production

The lab scale Rocking Kiln – Fluidized Bed was designed with the capacity up to 500 gram/hr. The lab scale RK-FB was developed at Malaysian Nuclear Agency and National University of Malaysia to produce bio char from palm kernel shell. The lab scale Rocking Kiln – Fluidized Bed consists of combination of the three components; the rocking kiln, rocking drive system and fluidized bed. The length of rocking kiln chamber is 900 mm and the internal diameter is 160mm. Air was blown through the small holes with 4 mm in diameters and located below the rotary kiln bed which cause it to become fluidized and the fluidized bed. The Rocking rate ranged from 2 to 5 seconds using pneumatic system. In the combustion process for RK-FB cold and hot run procedure were implemented.

The heating rate was controlled by controlling the amount of current LPG and oxygen passing through the burner. The temperature inside the kiln was 700°C and the temperature of the external or skin temperature was 160°C. The residence time and the heating rate were recorded.

There are primary chamber, combustion chamber and secondary chamber as shown in RK-FB drawing in Figure (1). The primary chamber section consists of LPG burners and biomass residues inlet. The chamber combustion part is the place where combustion took place. In combustion chamber, there are fine holes for fluidization and rocking of the system. The secondary chamber is the separation of the flue gas and collection of the product.



FIGUREURE 1: Schematic Diagram for RK-FB

C. Cold Run and Hot Run Process

The cold run and hot run processes with biomass waste were conducted in this work. The purposes of the experiments conducted in the two procedures were to study the efficiency of the rotary kiln and to gain the initial data during the cold run process and the true data during combustion or hot run process.

Cold run process was conducted using air. Rocking method was implemented during the cold run process to obtain data on the total air that was needed and the rocking velocity to move the waste starting from the loading until the unloading at the combustion chamber.

Hot run process was conducted to obtain data for combustion process such as the temperature, residence time, rocking, flow rate needed to become fluidized, product quality and yield of the product. This system is operated by turning the burner so that the temperature inside the burner chamber reaches 700°C, after which the biomass residue of the palm oil shell will be measured. The burner then will be switched off, and the flow of air will be discharged to the combustion chamber. The rocking system is turned on while the palm kernel shell burnt and the carbonization process took place to convert to bio char. The bio char products were released in the secondary chamber.

III. RESULTS AND DISCUSSIONS

A. The proximate analysis and ultimate analysis of palm kernel shell

The palm kernel shells used in this experiment were taken from oil palm processing plant of Seri Ulu Langat Palm Oil Mill Sdn. Bhd, Dengkil, Selangor. Table (2) tabulated the proximate and ultimate analysis of palm kernel shell. It is observed that the volatile content is high 74.9%. This might contribute to the carbonization effect and the yield of the bio char produced.

The carbon content as shown in Table (2) is high 48.9%, compared to the another study done by (Nor Afzanizam, 2015). From the literature (Nor Afzanizam,2015), the characteristic of the palm oil kernel shell were volatile matter 71.1%, fixed carbon is 18.8% and ash 4.7%. Table (2) shows that there are variations of the values from the raw material which may be due to factors on the quality of the trees and storage (Ghani et al., 2010).

TABLE 2: THE PROXIMATE AND ULTIMATE ANALYSIS OF THE PALM KERNEL SHELL (Isa et.al., 2018)

Palm Kernel Shell			
	This Work	**Nor Afzanizam, 2015**	**Raja Razuan, 2011**
Proximate Analysis (%)			
Volatiles	74.9	71.1	73.7
Fixed Carbon	21.5	18.8	18.4
Ash Content	2.1	4.7	2.2
Moisture	1.1	5.4	5.7
Ultimate Analysis (%)			
Carbon	48.9	48.1	53.8
Hydrogen	5.9	6.4	7.2
Nitrogen	0.6	1.3	0.0
Sulphur	0.2	0.1	0.5
Oxygen	41.4	34.1	36.3

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B. Production of Bio Char

Cold run and hot run processes were conducted to produce bio char in the Rocking kiln-Fluidized bed system. From the results, it was found that the suitable fluidized is 200 – 300 l/minute and 25 minutes of residence time was needed for the waste to complete the cycle.

The results also showed that combination of rotary kiln, rocking and fluidized bed produced a system that is able to move the biomass waste. The rocking method that was implemented in the system was to ensure that the waste would mix with the air during combustion. The rotary kiln must be rotated at an angle of 7°. The success of fluidized method depends on the total holes located at the bottom part of the rotary kiln. As a result, a large surface area will be produced and this will speed up the waste combustion process.

Hot run or combustion process is another step after obtaining the initial data results from the cold run test. In the hot run method, the operating temperature of the kiln was in range of 680°C – 720°C, which is the normal temperature of the kiln. At this temperature, the combustion of waste took place and was supported by rocking and fluidized to ensure that the combustion process is even. Set-up experiment for the hot run method is shown in Figure (2).

FIGUREURE 2: Combustion of biomass waste in the Rocking Kiln – Fluidized Bed

The product produced from rocking Kiln-Fluidized Bed or yield is defined as the percentage of the weight of the final product of carbonization from the initial material weight. Note that the yield does not include the ash content derived from the initial material, which is not removed by any treatment simulating of producing bio char.

The proximate and ultimate analyses of products produced from experimental results are listed in Table (3). The result of the product at temperature 680°C - 720°C is about 30-35% yield and carbon content is about 67.01%. The yield shows a decrease with an increase in temperature (Norfadhilah et al., 2019). This agreed with the work of (Abechi, 2013), lower yield is expected at higher temperature as more volatiles are removed. The rate of decrease is faster in the temperature range more than 400°C, which is characteristic of the behavior of the carbonization process. Produced the yield of carbon char about 29% at 600°C using the same raw material (Yang et al., 2006). (Stanislaw et al., 2018), used pyrolysis process found that the carbon content increases from 50% to 63% with increases in process temperature from 300°C to 400°C. When the temperature increased from 200-500°C, the carbon char yield decreases from 99.3% to 26.8% in wheat straw carbon char and 98% to 35.8% in pig manure carbon char (Liu et al., 2015). Carbon char produced from eucalyptus tree bark was 68% and corncob was 33% (Kanouo Djousse et al., 2017). From pyrolysis process conducted by Stanislaw (2018), total mass produced depending on the temperature with 50.07% mass yield of carbon char at 400^{0}C and 88.57% mass yield of carbon char at 300^{0}C.

TABLE 3: THE PROXIMATE AND ULTIMATE ANALYSIS OF THE PRODUCT

Proximate Analysis (%)		Ultimate Analysis (%)		Calorific Value (MJ/KG)
		Carbon	67.01	33
Volatiles	21.53	Hydrogen	3.41	
Fixed Carbon	75.90	Nitrogen	0.74	
Ash Content	2.25	Sulphur	0.20	
Moisture	1.2	Oxygen	12.59	
		Ash	2.00	

Table (3) shows the elemental composition found in the ultimate analysis. The elemental compositions were Carbon (C), hydrogen (H) and oxygen (O) which are the main components in the analysis. This results agreed with the work of (Ghani et al., 2010). During carbonization C and H are oxidized to form CO_2 and H_2O. The content of C and H contributes to the positive calorific value (Ghani et al., 2010). The calorific value after carbonization is much higher that is 33 MJ/kg as compared to the calorific value of the raw palm kernel shell without underwent carbonization process that is only 24 MJ/KG. According to (Ghani et al., 2010), the high calorific value is due to the high carbon content in the sample.

C. Effect of the air fluidization for the production of Bio Char

The temperatures were set at 680-720^{0}C at angle 7 degrees. From the experiments, the total air flow rate in the range of 50 – 850 l/m. From Figure (3) the air flow rate in the combustion chamber was 50 l/m. This resulted in 94% burnt of palm kernel shell with residence time of 60 min. However, the amount of bio char produced was 4% and the quality of the bio char was 32 MJ/kg. At 800 l/m flow rate the quality of the charcoal produced was low and approaching the quality of original palm kernel shell with low residence time. This shows that with high flow rate the palm kernel shell was not able carbonized.

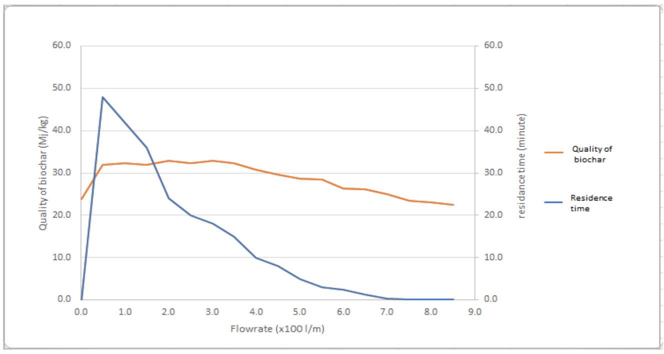

FIGURE 3. EFFECT OF THE AIR FLUIDIZATION FOR THE PRODUCTION OF BIO CHAR

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Figure (3) showed the optimum air flow rate to produce quality and quantity bio char. At air flow rate of 200 l/m, residence time 20-25 min, amount of bio char produced were 30-35% with 33 MJ/kg. This shows that only 30-35% of bio char produced from 100% raw palm kernel shell. According to (V. Idakiev et al., 2013), the residence time is influenced by the air flow that enter the chamber. In his study, the materials dispersed in continuous operation while the residence time decreased as the flow rate increased.

The charcoal production from the combustion is affected by the amount of air flow rate. The air flow rate also affects the residence time of the raw material in the combustion chamber until the product is released.

D. Effect of the Rocking Angle

Figure (4) shows the effect of the rocking angle of the system. The angle effects the quality of the product and the produced yield. In this work, the flow rate was at 200 l/m and 300 l/m with temperature at 680°C-720°C. At flow rate 200 l/m and 300 l/m with 2 degree rocking angle, the yield was 15% and the quality bio char produced was 30 MJ/Kg. This is due to only 15% was produced when 100% biomass waste inserted in the RK-FB combustion chamber. This is due to small angle and long residence time 55 minutes cause the bio char burnt stated that the angle of the rotary kiln effect the bio char produced. Further increased in the angle will cause inadequate residence time for feed to complete the combustion (Gajendra Kumar et al., 2014).

From Figure (4) at angle 7 degree, highest production bio char at 30% with high quality at 33 MJ/kg and residence time at 20-25 minutes. With the same flow rate, a 200 l/m and 300 l/m, the difference is only 5%. Thus the optimum angle was at 7 degree

At angle 10 degree, the yield was 35%, however, the quality of the product decreased at 28 MJ/kg. When the angle increased, the carbonization happened in shorter time and most of the kernel shells did not carbonized efficiently.

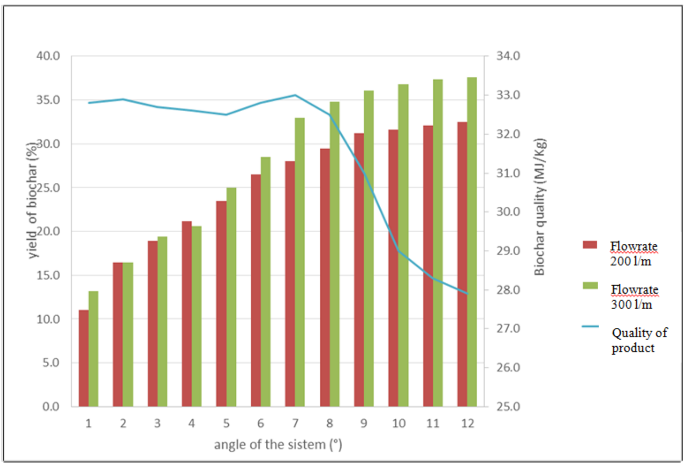

FIGURE 4. EFFECT OF THE ROCKING ANGLE IN THE PRODUCT PRODUCED.

E. New Parameters for RK-FB

In this study, a new concept of laboratory lab scale system was developed which combines the three components which are the rotary kiln, rocking and fluidized bed made the system work efficiently. According to the literature (National Guidelines for Hazardous Waste Incineration Facilities, 1992) the combustion temperatures vary according to the characteristics of the waste material but in general the range is between 810°C – 1650°C. However, the operating temperature for Rocking Kiln-Fluidized Bed which is used in this research is much lower that is starting from 680°C – 720°C. The European Von Roll organization which produces a rocking kiln which is the same as a rotary kiln with rotation at 45 degree from centre in each direction also has the operating temperature from 600°C – 1300°C which is slightly higher than the operating temperature for RK-FB produced and (National Guidelines for Hazardous Waste Incineration Facilities., 1992). The new parameters used in this research are tabulated in Table (4).

TABLE 4: NEW PARAMETERS USED IN THIS WORK

Parameters	**Units**
Temperature	680°C - 720°C
Air Flowrate	200 – 300 l/m
Rocking displacement	90°
Angle of the rotary kiln	7 degree
Residence time	20 – 25 minutes
Weight reduction of palm oil kernel shells	70%

IV. CONCLUSION

From the experimental results, cold run and hot run process can be used to obtain combustion parameters. The optimum parameters obtained from cold run process were total air for fluidization at 200 – 300 l/min, the rocking angle was at 7 degree and residence time at 20-25 minutes while the hot run process obtained the suitable parameter for this new system to work efficiently were temperature 680°C-720°C, flow rate at 200-300 l/m, angle of the rotary kiln at 7 degree and weight reduction of palm oil kernel shells at 70%. This system is capable to process biomass waste with complete combustion to produce energy and carbonization for production of charcoal. The produced bio char have calorific value, 33MJ/Kg.

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