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Efficiency of the Rocking Kiln – Fluidised Bed for Charcoal Production

(Kecekapan Pembakar Tanur Berputar – Lapisan Terbendalir (RK-FB) bagi Penghasilan Arang)

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ABSTRACT

Rocking Kiln – Fluidised Bed (RK–FB) combustor is a system using thermal technology for processing biomass waste. This system is capable of processing biomass with complete combustion to produce energy and carbonisation for production of biomass – derived fuel (BDF) pellet. A research has been done to transform the biomass waste such as kernel shell into BDF using the newly invented RK-FB technology. This research was also conducted to obtain preliminary data parameters such as the suitable temperature, the angle of the system, residence time, total air for fluidization, rocking speed and reduction of weight sample. The samples used in this research were the palm oil kernel shells. The results of the studies showed that the palm oil kernel shells were combusted evenly using the new parameters; temperature, angle of the rotary kiln, residence time and rocking oscillation frequency, rocking displacement, weight reduction of palm oil kernel shells after combustion and calorific value of product produced and soaking the palm kernel shells in the phosphoric acid solution shows better results than without soaking the palm shell in the phosphoric acid before combustion. The produced charcoal has calorific value of 33 MJ/kg which is better than bituminous coal with calorific value, 25-30 MJ/kg. Due to the high calorific value of the charcoal produced, hence charcoal can be used for the energy production.

Keywords: Biomass waste; Combustion; Incineration technology

ABSTRAK

Tanur Berputar – Lapisan Terbendalir (RK–FB) merupakan sistem yang menggunakan teknologi terma untuk memproses sisa biojisim. Sistem ini mampu memproses sisa biojisim dengan pembakaran lengkap untuk menghasilkan tenaga, penghasilan karbon untuk pengeluaran pelet bahan bakar terbitan biojisim (BDF). Satu penyelidikan telah dilakukan untuk mengubah sisa biojisim seperti tempurung kelapa sawit kepada BDF atau karbon menggunakan teknologi RK-FB yang dicipta. Kajian ini juga dijalankan untuk mendapatkan parameter data awal seperti suhu yang sesuai, sudut sistem, masa, jumlah udara, kelajuan sistem pusingan dan pengurangan berat sampel. Sampel yang digunakan dalam kajian ini adalah tempurung kelapa sawit. Hasil kajian menunjukkan bahawa tempurung kelapa sawit di bakar dengan menggunakan parameter baru; suhu, sudut kebuk berputar, masa dan kekerapan ayunan, anjakan sistem, pengurangan berat tempurung kelapa sawit selepas pembakaran dan nilai kalori hasil produk dan dengan merendam tempurung kelapa sawit dalam larutan asid fosforik juga menunjukkan hasil yang lebih baik daripada tanpa merendam tempurung kelapa sawit dalam asid fosforik sebelum pembakaran. Karbon atau arang yang dihasilkan mempunyai nilai kalori, 33 MJ/kg yang lebih baik daripada arang batu bitumen dengan nilai kalori, 25-30 MJ/kg. Oleh kerana nilai kalori tinggi karbon atau arang yang dihasilkan, maka karbon atau arang ini boleh digunakan untuk pengeluaran tenaga.

Kata kunci: Sisa biomas; Pembakaran; Teknologi insinerasi

INTRODUCTION

Most significant biomass source in Malaysia comes from oil palm industries. According to Shafie et al. (2012), in 2009, Malaysia has approximately 4.75 million hectares of palm oil under cultivation which covers about 60% of the country's agricultural area. According to a report in 2014 by Malaysia Palm Oil Board (MPOB), Malaysia is the second world`s largest supplier of palm oil after Indonesia and supplying 30% of the world demands on palm oil (Choo 2014). This scenario is expected to continue due the rise in demand on crude palm oil (CPO) production in 2018, which is projected at 20.50 million tonnes, rose up by 2.9% as compared to 19.92 million tonnes in 2017 (Kushairi 2018). The rising demand is due to expectation of better yield performance as well as increase in oil palm matured area (Kushairi 2018).

The oil palm industries also generated biomass waste from milling and crushing of palm oil. According to Choo (2014), the production of biomass wastes such as palm kernel shell and palm fibre are as follows:

1. Kernel shell = 5.2 million tonnes/year
2. Fibre = 7.69 million tonnes/year

Since Malaysia is the second highest production in this industry, the abundant biomass waste such as palm kernel shell can be utilized for potential commercialization in producing energy from biomass. Palm shell has considerably high carbon content and since it is one of the primary agricultural in Malaysia, the price of the palm shell is relatively low and usually is treated as the biomass waste. The palm kernel shell has the highest content of carbon (55.7%) compared to oil palm fibre (49.6%), coffee shells (50.3%) and sugar cane (53.1%) (Evbuomwan et al. 2013).

Biomass conversion to energy production can be achieved using combustion technology, anaerobic digestion and pyrolysis (Abdullah et al. 1996; Islam & Ani 2000). Examples of combustion technology are rotary kiln, fluidised bed, rocking kiln, bed grates furnace and combustor. Rotary kiln technology involves rotation method and the residence time depends on the length and diameter of the rotary kiln and the total stoichiometric air supplied to the system. The rocking system is another technology used in combustion. In the rocking system, internal elements in the combustion chamber move to transport and mix the burning waste so that all combustible materials in the waste are entirely burnt. Another technology in combustion is the fluidised bed technology. This method uses air and sand. The total air is controlled to obtain a suitable fluidisation. Total air holes located below the fluidised bed system is also one of the factors that contribute to its performance.

This research will study the efficiency of a combustion system made from combination of three components namely rotary kiln, rocking system and fluidised bed. The newly developed technology is called Rocking Kiln – Fluidised Bed (RK–FB). This research was also conducted to obtain data parameters of the three components such as suitable temperature, system angle, residence time, total air for fluidisation, rocking speed and reduction of weight sample. The samples used in this research were the palm oil kernel shells.

METHODOLOGY

BIOMASS CHARACTERIZATION AND SAMPLE PREPARATION

Characterizations of the biomass (biomass waste) were done using proximate analysis, ultimate analysis and calorific value with standard methods ASTM D 3286-96 and ASTME 711-87. In carbonization process, the sample (palm oil shell) was soaked with a chemical agent which is phosphoric acid. In this work, the samples were soaked in the phosphoric acid in a ratio of 1:2 and the samples were left overnight in an ambient temperature. Before the sample was fed into a reactor, the sample was washed with distilled water to remove the residual acid and the sample was dried in the oven at 85°C for 8 hours. Finally, the sample was fed into a rector in which case it was converted into carbon.

EXPERIMENTAL RIG FOR CARBON CHAR PRODUCTION

RK–FB is one of the suitable incinerator systems to process biomass waste. Biomass waste has different shapes, sizes and values of heating and it can be put RK–FB either gradually or continuously. This system uses a thermal method whereby it converts biomass waste into charcoal and gas vapour. The system is equipped with a burner where it acts as a flame ignition. The system is equipped with an air injection system to ensure the occurrence of turbulent flow in the system and to increase the combustion process where the amount of air can be controlled to obtain the appropriate fluidised. The system combusts on its own when the temperature in the RK–FB reaches 700^{o}C. At this time the fuel source that is the LPG will be cut off and the biomass waste will be self-burnt during the carbonisation process. RK–FB reactor was designed to convert biomass waste into carbonaceous material. The reactor is a modular, prefabricated reactor. A typical embodiment of the combustor apparatus is illustrated in Figure 1. The components of the reactor are:

1. Primary chamber
2. Combustion chamber
3. Secondary chamber

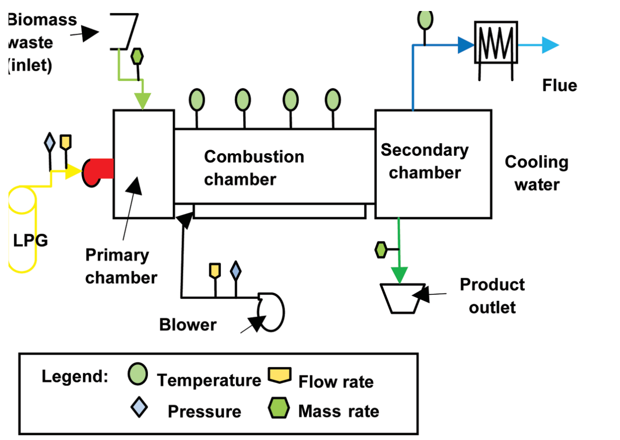

FIGURE 1. Rocking Kiln Fluidised Bed (RK–FB)

The RK–FB was designed based on specification where the length of the rocking kiln fluidised bed is 1900 mm with the internal diameter of 160 mm. The fluidised bed feeder can cater up to 2 kg/cm^3 and the rocking rate can range from 2-5 s using the pneumatic system. The rotary kiln reactor was designed with special attention given to enhancing the transportation of the rocking kiln product. The heating rate was controlled by adjusting the amount of current liquid propane gas (LPG) and oxygen passing through the burner. The residence time and the heating rate were recorded. The temperature inside the kiln can be up to 700^{o}C, and the temperature of the external or skin temperature can reach 560^{o}C. The air that was supplied through the small holes with 4 mm in diameters is located below the rotary kiln bed, causing it to become fluidised. The pneumatic cylinder was used to get a rocking kiln and to rotate only 90° from the centre in each direction.

Referring to the Schematic diagram, there are 3 main components in the system, namely primary chamber, combustion chamber and secondary chamber as shown in Figure 2. The system features gauge for temperature, flow meter, pressure and mass rate. The primary chamber section is the part where LPG burners and biomass residues are in the system. The chamber combustion part is the place where combustion takes place. In this section there are fine holes for fluidization and rocking of the system. While the secondary part is the separation of the flue gas and the product it collects.

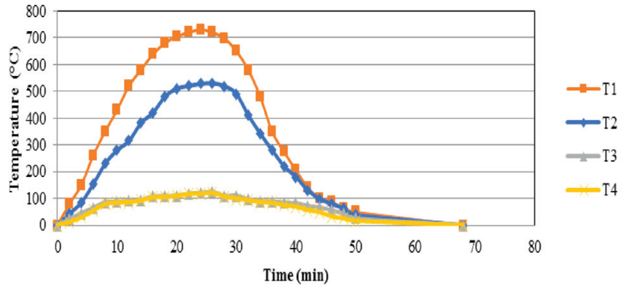

FIGURE 2. Schematic diagram of the RK–FB

This system is operated by turning the burner first so that the temperature inside the burner chamber reaches 700^{o}C, after which the biomass residue of the palm oil shell will be measured before it is included in the system. The burner will be switched off, the flow of wind will be discharged to the extent of its own combustion in the combustion chamber. While the rocking system will turn on and the palm kernel shell will burn and the carbonization process takes place to convert to carbon (charcoal). The result of combustion will release the smoke and the resulting product will be released in the secondary chamber.

RESULTS AND DISCUSSION

PALM KERNEL SHELL CHARACTERISTICS

The raw material, palm kernel shells used in this experiment were taken from palm oil processing plant in Dengkil, Selangor. Table 1 shows the proximate and ultimate analysis of the raw material. The volatile content was high (74.9%), which might contribute to the activation effect and the yield of the activated carbon. Table 1 also shows the carbon content was neither high (48.9%), which is of interest in this study of carbonisation process if compared to another study done by Samiran et al. (2015). The author reported the characteristic of the palm oil shell were: volatile matter 71.1%, fixed carbon is 18.8% and ash 4.7%.

TABLE 1. Proximate and ultimate analysis of palm kernel shell and coconut shell

	This work (Palm kernel shell)	Samiran et al. 2015 (Palm kernel shell)	Yield of the carbonization process (charcoal produced)	Iqbaldin et al. 2013 (Coconut shell)
		Proximate Analysis (%)		
Volatiles	74.9	71.1	21.53	77.82
Fixed Carbon	22.5	18.8	75.90	21.38
Ash Content	2.1	4.7	2.25	0.8
Moisture	1.1	5.4	0.2	–
		Ultimate Analysis (%)		
Carbon	48.9	48.1	80.01	49.62
Hydrogen	5.9	6.4	3.41	7.31
Nitrogen	0.6	1.3	0.74	0.22
Sulphur	0.2	0.1	0.20	0.1
Oxygen	41.4	34.1	12.59	42.75

*Calorific Value (MJ/kg) of the charcoal produced is 33 MJ/kg

Table 1 also shows the variations of the parameter values from raw material. These may be due to factor such as the quality of the tree and also the storage conditions (Wan Ab Karim Ghani et al. 2010). Table 1 shows high volatiles for coconut shell (77.82%) compared to palm kernel shell and ash content of coconut shell content is also low (0.8%). These signified a small amount of ash were left after combustion of coconut shells compared to palm kernel shell. The analysis also denotes the carbon content of palm kernel shell and coconut shell was almost similar. These indicate that palm kernel shell is high-quality charcoal.

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. The high calorific value is due to the high carbon content in the sample (Wan Ab Karim Ghani et al. 2010; Sing & Aris 2013).

NEW PARAMETERS FOR RK–FB REACTOR

As a result of the combustion on palm oil kernel shells, the weight of the sample reduced to 70% and it was formed in carbon state. The results of this method are shown in Table 2. Combustion process after the weight of the sample reduced to 70% was lead to formation of carbonization process, and almost all hydrocarbon group such as C-H, C=O, C-O and C=N were destroyed. The production of CO was proposed from the cleavage of carbonyl groups (C=O) and of the bonds C–O, C–O–C, and C–C, and the production of CH_4 was mainly caused by the cleavage of methoxyl groups (–O–CH_3) and the break of methylene (Tihay & Gillard 2010).

TABLE 2. Total weight reduction after combustion

Weight Sample (g)	Temperature (°C) Time (min)	Residence Time (min)	Weight Reduction After Combustion
250	700	20	70%

EFFECT OF COMBUSTION TIME

During the process carbonization, the combustion temperature inside the RK–FB is important to determine the quality of product produce. Figure 3 shows that the combustion temperature rises to 700^{o}C for start-up and the burner will be turned off. The oil palm shell starts to be inserted into the system and air for fluidization in the stream. The temperature remains at 700 ± 20^{o}C. for 10 to 15 min carbonization process occurs. Then, the temperature will decrease and the resulting charcoal will experience cooling process after 30 minutes. Chiramonti et al. (2014) in their work used lower temperature at 450-500^{o}C for carbonization process of forest waste using pyrolysis biomass. However, in this work higher temperature were used at 700 ± 20^{o}C for this system due to excess air for fluidization and self-combustion.

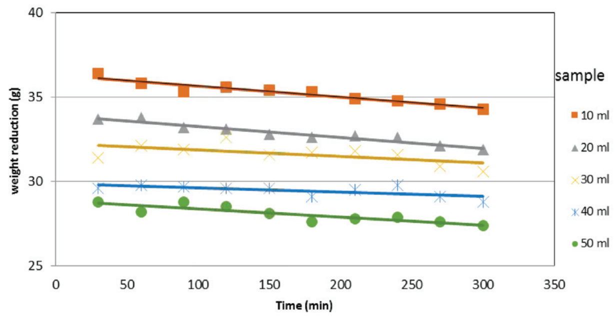

FIGURE 3. Effect of the combustion temperature inside the RK-FB system

CARBONIZATION OF PALM KERNEL SHELL WITHOUT SOAKED WITH PHOSPHORIC ACID

In this work, palm kernel shells were carbonized in the RK-FB without soaking in the phosphoric acid solution. As a result, the weight of the sample reduced to 70% to 80% (i.e. 20 – 30% yield) and it is in char state as shown in Table 3. It shows that as the residence time increased, the weight reduction increased from 68.90% to 79.81% where the lowest residence time is 20 min and the highest residence time is 30 min respectively. Besides the residence time, the tilt angle also influenced the results of the weight reduction. When the tilt angle is high, example at 8^o, the residence time is shorter that is about 20 min. The results of carbon content in the char material are shown in Table 4.

TABLE 3. Weight reduction after carbonization without soaked with phosphoric acid

Sample identification	Weight sample (g)	Temperature (°c)	Tilt angle of rotary rotary kiln reactor (°)	Feed material residence time (min)	Weight reduction after combustion
CC190617 (A)	100	680 ~ 710	8	20	68.90%
CC190617 (B)	100	680 ~ 710	7	25	71.84%
CC190617 (C)	100	680 ~ 710	6	27	75.84%
CC190617 (D)	100	680 ~ 710	5	30	79.81%

TABLE 4. The ultimate analysis of carbon content in carbon char

Sample Identification	C (%)	H (%)	N (%)	S (%)
CC190617 (A)	71.82	2.37	0.44	< 0.05
CC190617 (B)	74.63	1.94	0.49	< 0.05
CC190617 (C)	78.92	1.91	0.62	< 0.05
CC190617 (D)	79.75	2.10	0.47	< 0.05

Tilt angle and residence time will affect the weight reduction and production of carbon percentage in the carbon char because the combustion of palm kernel shell is not fully combusted. The carbon percentage in this experiment varies with the residence time accordingly. The average percentage of carbon content produced is 76.28% in Table 4.

CARBONIZATION OF PALM KERNEL SHELL SOAKED WITH PHOSPHORIC ACID

As a result of the partial combustion on palm shells with phosphoric acid, it was found that there is the weight of sample which has been reduced by 65 to 75% (i.e. 25 – 35% yield) and it is in char state as shown in Figure 4. The carbon content by ultimate analysis in the char material is about 79 – 82%. The combustion process produced carbon char was further investigated by combusted the palm kernel shells either soaked with phosphoric acid and without phosphoric acid. When the palm kernel shells soaked in the phosphoric acid, the yield produced about 25% to 35%, and they were in char state. This showed that there was a reduction of 65% to 75% of weight from the combustion using the RK-FB system and the carbon content produced in the char material is about 79 – 82%. On the contrary, 20% to 30% of yield produced using the RK-FB system for combustion of palm shells without soaking in the phosphoric acid. The weight of the samples was also reduced about 70% to 80%, and they were in char state and the carbon produced were in the average of 76.28%. The combustion process in producing carbon char was further investigated by combusting the palm kernel shells soaked with phosphoric acid and without phosphoric acid. When the palm kernel shells soaked in the phosphoric acid, the yield produced was about 25% to 35% and they were in char state. This showed that there were reductions of 65-75% of weight from the combustion using the RK-FB system and the carbon content produced in the char material was about 79 – 82%. On the contrary, 20% to 30% of yield produced using the RK-FB system for combustion of palm shells without soaking in the phosphoric acid. The weight of the samples was also reduced about 70% to 80% and they were in char state and the carbon produced were in average of 76.28%. This work involved carbonization method for production of charcoal. However, there is also another method engaged in the production of charcoal which is called the pyrolysis method. Antal et al. (1996) in their work, a charcoal reactor which uses the pyrolysis was presented. From their apparatus, the mass yields of charcoal from six biomass species (*Eucalyptus*, *Kiawe*, *Leucaena*, Macadamia nutshells, *Kukuinur* shells and Coconut husk) are in the range 42% to 65%. Another work on carbonization process using pyrolysis was done by Muhd Noor (1995) using palm oil as the raw material. From his work, the mass yields of charcoal obtained were about 20% – 30%. However, from this work which involved combustion, the mass yields of charcoal for palm kernel shell are in the range of 25% – 35% which depended on the method used. Table 5 shows the percentage of mass yield of charcoal during carbonization process from different raw materials using combustion method and pyrolysis method. The results show that the raw material (palm kernel shell) might affect the yield and quality of the charcoal significantly. Even though carbonization using pyrolysis method Antal et al. (1996). In this research, the advantage was the zero tar production during carbonization process compared to pyrolysis.

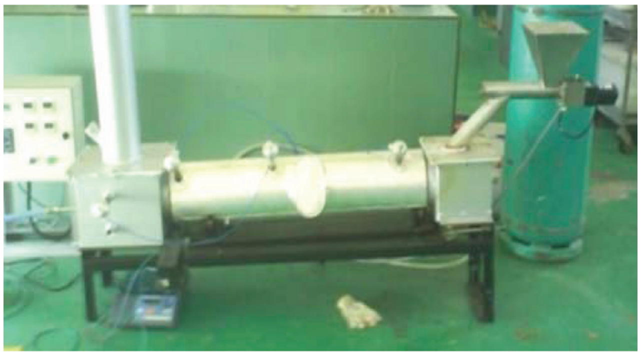

FIGURE 4. Weight reduction after carbonization soaked with phosphoric acid

TABLE 5. Percentage of mass yield of charcoal

Method	Raw material	Mass yield of charcoal (%)	References
Carbonization	Palm kernel shell	25 - 35	(this work)
Pyrolisis	Palm kernel shell	30 - 31	Muhd Noor, (1995)
Pyrolisis	Macadamia shell	42 – 65	Antal et al. (1996)

CONCLUSION

From the experimental results, the RK-FB reactor is suitable for treatment of biomass for energy production. From this work, the carbon content produced using the newly design RK-FB was more than 80%. In this study, the optimum temperature that was set to the RK-FB system in achieving the 25 – 35% mass yield of charcoal produced is 600 – 700°C. The rocking displacement for this system was 90°. The angle of the rocking kiln was 6°. The optimum time for the residence time was 20 min, and the rocking oscillation frequency was 2-3 s to produce high quality carbon char. Quality of the carbon char produced can be increased when soaking in the phosphoric acid. The carbon content in this carbon char was about 79 – 82% (ultimate analysis) and the charcoal produced have calorific value, 33 MJ/kg.

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