# MECHANICAL AND COMBUSTION CHARACTERISTICS OF OIL PALM BIOMASS FUEL BRIQUETTE

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***ABSTRACT***

*Palm Kernel Shell (PKS) and Mesocarp Fiber (MF) are residues from oil palm which are treated as waste in most oil palm production mills. PKS was pulverized and sieved into different grain particle sizes of 350 μm, 250 μm and 150 μm. The pulverized PKS were then mixed with MF in the ratios 90:10, 80:20 and 70:30, respectively, with cassava back peel as the binder. After thorough mixing, a 200 kN force was placed on each sample in moulds to form briquette. Mechanical and combustion characteristics of the briquettes were determined to ascertain their efficiency as solid fuel. The results of the mechanical assessment revealed that the fuel briquette with 90% PKS of 350 μm and 10% MF displayed poor mechanical strength compared to other samples while fuel sample with 90% PKS of 250 μm and 10 MF gave best results in terms of the combustion property.*

***KEYWORDS****: Oil palm; biomass fuel briquette; mechanical characteristics; combustion characteristics*

## 1.0 INTRODUCTION

About 80% of the energy sources today are obtained from fossil fuels which are mainly coal, crude oil and natural gas. Researches have proven that these sources are tending to extinction (Emerhi, 2011). Therefore, the need to reinvigorate a new means of energy sources which can substitute non-renewable sources especially for developing countries becomes eminent. Currently, research works to properly utilize the tonnes of agricultural wastes generated yearly has not been maximally

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explored. However, recent studies have shown that agricultural wastes or residues may be converted to useful products if properly managed. Oil palm waste is very reliable source of renewable energy due to its availability, continuity and capacity (Abdullah & Sulaiman, 2013). About 10 – 15% of edible oil can be obtained from oil palm tree, where most of the remaining residue of between 85 – 90% is mainly treated as biomass wastes. In 1998, about 90 million tonnes of oil palm fruit production were recorded in Nigeria, 43 – 45% of which were milled residues in the form of empty fruit bunch, shell and fiber (Abdullah & Sulaiman, 2013). Palm fronds and stems are currently under-utilized, and the oil palm waste has created a major disposal problem. Therefore, maximizing energy recovery from the biomass residue is desirable for better waste management and economic reasons.

Deforestation rate will continue to increase if nothing is done to forestall the use of wood as major source of fuel in rural areas. This can achieved by promoting the use of biomass such as mesocarp fiber and palm kernel shell from palm tree as shown in Figures 1, 2 and 3 which is relatively in abundance especially in most rural areas within the country. Biomass have gained recognition since almost zero net carbon dioxide accumulation in the atmosphere can be achieved from its utilization. Consequently, carbon dioxide released the during combustion process is compensated by the carbon dioxide consumption during photosynthesis (Abdullah & Sulaiman, 2013).

The present study is aimed at fostering more interest in the use of oil palm tree residues for the production of fuel briquette that can successfully replace charcoal and wood for domestic and industrial use. Conversion of these wastes to energy sources can also substantially reduce the dependency on kerosene for fossil fuel, reduce greenhouse gases emissions and provide renewable energy to millions of people in developing countries such as Nigeria (IETC, 2009).

Figure 1. Oil palm tree

Figure 2. Mesocarp fiber

Figure 3. Palm kernel shell

## 2.0 MATERIALS AND METHOD

### 2.1 Materials Preparation and Sorting

The as-received palm kernel shell (PKS), mesocarp fiber (MF) and cassava peel (CP) were pre-treated by washing so as to remove every form of dirt and foreign materials such as sand, stone, ashes and plant residues which may be detrimental to the fuel briquette. This was followed by sun drying in order to allow for proper grinding of the mixtures.

### 2.2 Crushing and Sieving

The PKS was crushed by a local grinding machine and later sieved with Octagon Digital Sieving Machine at the department of Geology and Mineral Sciences, University of Ilorin, Nigeria. It was sieved to 350 μm, 250 μm and 150 μm according to the British Standard (BSS).

### 2.3 Mixing Ratios

Crushed palm kernel shell, mesocarp fiber and cassava peel were thoroughly mixed in different proportions to enhance the homogeneity of the fuel briquettes. The formulation adopted in this work is illustrated in Table 1. The quantity of binder (cassava peel) and water used were constant for the entire mixing ratio and particle sizes.

Table 1. The mixing ratios of palm kernel shell, mesocarp fiber and cassava peel at different particle sizes

| Biomass materials | Palm kernel shell (g) | Mesocarp fiber (g) | Cassava peel (g) | Water |
|---|---|---|---|---|
| 90:10 | 63 | 7 | 30 | 500 ml |
| 80:20 | 56 | 14 | 30 | 500 ml |
| 70:30 | 49 | 21 | 30 | 500 ml |

## 2.4 Densification

Mixing of the aggregates, PKS and MF with the binder was done using a manual stirrer. After thorough mixing, the feedstock was then poured into the prepared mould (Figure 4) prior to compaction using 1560 kN manual hydraulic jack machine, model EL31 072 (Figure 5). During compaction, the mould was placed in between the compressive plates of the machine before releasing the piston, which exerts a force of 200 kN on the aggregates to produce fuel briquette (Figure 6). The dwelling time was 120 seconds for every briquette produced. For reliability sake, each proportion of the aggregates was iterated four times. The briquette samples were then sun dried for 2 weeks so as to allow for drying of the residual moisture.

Figure 4. Dismantled mould

Figure 5. Hydraulic Jack Machine

Figure 6. Briquette Sample

## 2.5 Mechanical Properties of the fuel samples

The mechanical property of any solid fuel is important in order to improve the handling, transportation and storage capacity of the briquettes. Mechanical tests carried out in this study include durability analysis, water resistance test and crack analysis.

### 2.5.1 Durability Analysis

The durability test was carried out according to the method of Al-Widyan, Al-Jalil, Abu-Zreig & Abu-Hamdeh, 2002. The briquettes were dropped from a height of 1.85 m onto a flat steel plate for four times. The percentage durability was calculated as the ratio of the final weight of material retained after four drops to the initial weight of the briquettes as shown in Equation (1) (Al-Widyan et al., 2002).

$$\text{Durability (\%)} = \frac{\text{Weight of the sample in plate after 4 drops}}{\text{Initial weight of the sample}} \text{ X } 100 \qquad (1)$$

### 2.5.2 Water Resistance Test

The briquette samples were immersed in a container filled with cold tap water and the time required for dispersion in water was recorded (Demirbas, 1999).

### 2.5.3 Crack Analysis

The crack test was carried out using the method of Husain et al., (2002). The briquette samples were allowed to fall freely from a height of 1-2 m and the resulting crack length was measured.

## 2.6 Combustion Characteristics of the Briquette samples

The combustion characteristic of any solid fuel is an integral aspect of briquette production as it shows the quantity of energy in the briquettes. In this study, porosity index, ignition time and water boiling tests were carried out while burning rate and specific fuel consumption were estimated.

### 2.6.1 Determination of Porosity of the Briquette Samples

It was done according to the method of Piersol, 1948, though the time of immersion was reduced to 15 minutes due to the nature of the current samples. The briquette sample of a known weight (initial mass) was immersed in equal volume of water in different beaker. The briquette was removed and excess water was allowed to drain out for about 25 sec. The sample was then re-weighed to determine the final mass so as to estimate for the porosity. The porosity index was then estimated using Equation (2) (Piersol, 1948).

$$\text{Porosity Index} = \frac{\text{Mass of water absorbed}}{\text{Mass of the sample.}} \quad (2)$$

### 2.6.2 Determination of the Ignition Time

The briquette samples were ignited at the base in a drought free corner. As the flame ignites the briquette, the ignition time was taken using a stop watch (Eboatu et al., 1992 & Eboatu et al., 1993).

### 2.6.3 Water Boiling Test

It is a measure of the time taken for each set of briquettes to boil an equal volume of water under similar conditions in order to test for the cooking efficiency. 100 g of each briquette sample was used to boil 100 cm3 of water using small stainless steel pot and domestic briquette stove (Kim et al., 2001). Burning rate and specific fuel consumption were determined from the test using Equations (3) and (4) (Jean & Owsianowski, 2009), respectively. Evolution of the briquette smoke was also noted.

$$\text{Burning Rate} = \frac{\text{mass of fuel consumed (g)}}{\text{Total time taken (min.)}} \quad (3)$$

$$\text{Specific Fuel Consumption} = \frac{\text{mass of fuel consumed (g)}}{\text{Total mass of boiling water (l)}} \quad (4)$$

## 3.0 RESULTS AND DISCUSSION

### 3.1 The Mechanical Properties of the fuel briquettes

#### 3.1.1 Durability and Water Resistance tests

Figure 7 shows the durability test of different composition of the fuel briquettes while the water resistance duration of each of the briquettes is presented in Figure 8. It is evident from Figure 7 that 150 μm (70:30) has the highest durability as a result of higher amount of mesocarp fiber in the aggregate. This observation agrees with the finding of Chin Yee & Shiraz (2012), which revealed that mesocarp fiber displayed higher durability of 97.6% than palm kernel shell with 85.3%. The figure also revealed that the durability of briquette with PKS:MF (80:20) is higher than that of PKS:MF (90:10) at 150 μm, indicating that MF played a prominent role in promoting the durability property of PKS:MF solid fuels. That is, the higher the amount of fibrous mesocarp in the PKS:MF fuel briquette, the higher the durability of the briquette.

The grain particle size of the PKS is another important parameter that affects the percentage durability of PKS:MF briquettes as shown in Figure 6. The Figure showed that the finer the grain sizes, the higher the durability of the briquette. Series 350 μm briquettes at different PKS and MF aggregates gave the least durability percentage and thus briquette sample 350 μm (90:10) has a durability percentage of 88.43%, which is the least among all the nine samples. This is due to the combined effect of low amount of mesocarp fiber and higher grain size of PKS in the aggregate.

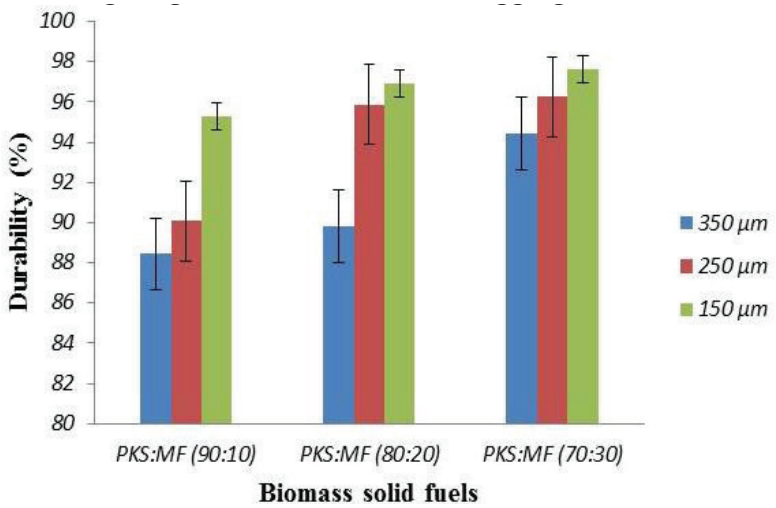


Figure 7. Durability of the biomass solid fuels in their respective particle sizes and mixing ratios

Figure 8 shows the time taken before the fuel briquettes begin to dissolve when exposed to water. It is revealed from the Figure that fuel briquette (70 g) of 150 µm (70:30) spent more time to collapse when exposed to water, taking up to 23 min 40 sec. This was followed by 150 µm (80:20) and 150 µm (90:10). The results showed that briquette with finer grain sizes and higher percentage of mesocarp fiber will resist water penetration better than those with coarse grain sizes and less amount of mesocarp fiber. As shown in Figure 7, briquettes with higher PKS grain size, 350 µm displayed less resistance to water penetration and thus collapsed faster compared with samples with 250 µm and 150 µm PKS aggregate. This shows that resistance of fuel briquettes in water is dependent not only on the grain sizes but also the amount of fibrous mesocarp in the aggregates. However, according to Chin Yee & Shiraz (2012), it only took 9.99 s for 60PKS:40PF to dissolve in water. This may be due to smaller weight of their samples, which is 10 g each, compared with 70 g of each fuel briquette used in the current study.

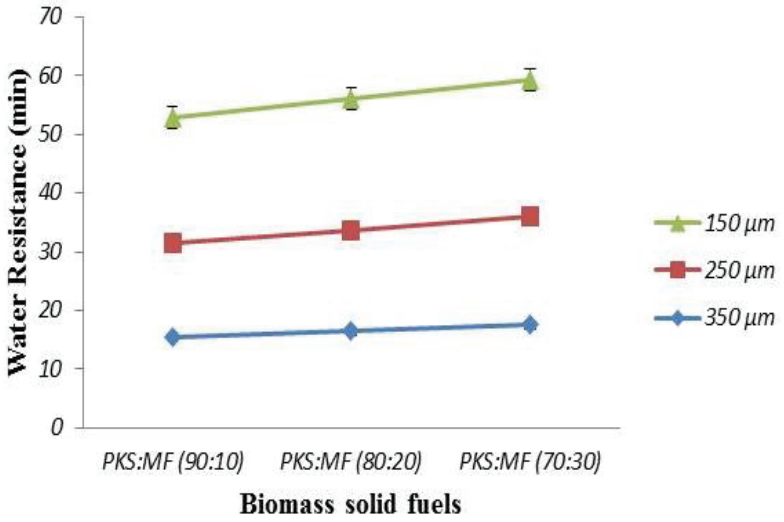


Figure 8. Water resistance duration of palm kernel shell and mesocarp fiber briquette samples at different grain particles and mixing ratios

Table 2 shows the comparison between the durability percentage and water resistance duration of the fuel samples in the current study with some previous work. The 9.99 s reported by Chin Yee & Shiraz (2012) for the fuel briquette to dissolve in water is comparable smaller than all those of the current study, which might actually due to the smaller size of the briquette produced in their own study. However, the results obtained in this study still shows that the fuel samples are mechanically viable and can withstand sudden drop up to 1.85 m consistently for four times and as well capable of resisting moderate water when exposed to rain or high humidity conditions during transportation and storage as reported by Kaliyan & Morey (2006).

Table 2. Durability and water resistance of PKS: MF aggregate as biomass solid fuels in different mixing ratios and particle sizes and other biomass solid fuels

| Biomass Solid Fuels | Grain Particles (μm) | Durability (%) | Water Resistance | References |
|---|---|---|---|---|
| **90PKS:10MF*** | 350 | 88.43 | 15.40 min | Present study |
| **80PKS:20MF** | 350 | 89.80 | 16.42 min | Present study |
| **70PKS:30MF** | 350 | 94.40 | 17.50 min | Present study |
| **90PKS:10MF** | 250 | 90.07 | 16.00 min | Present study |
| **80PKS:20MF** | 250 | 95.86 | 17.30 min | Present study |
| **70PKS:30MF** | 250 | 96.24 | 18.45 min | Present study |
| **90PKS:10MF** | 150 | 95.30 | 21.39 min | Present study |
| **80PKS:20MF** | 150 | 96.90 | 22.38 min | Present study |
| **70PKS:30MF** | 150 | 97.60 | 23.40 min | Present study |
| **PKS** | | 85.30 | --- | (Chin Yee & Shiraz, 2012) |
| **PF** | | 97.60 | --- | (Chin Yee & Shiraz, 2012) |
| **60PKS:40MF°** | 63-500 | 98.70 | 9.99 sec | (Chin Yee & Shiraz, 2012) |

*PKS: MF = Palm kernel shell: Mesocarp fiber °PKS: PF = Palm kernel shell: Palm fiber

### 3.1.2 Crack Analysis

Figure 9 is a pictorial illustration of the briquette samples as produced in the present study. The extent of crack formation on the briquettes are summarized in Table 3. Virtually all the briquettes display good mechanical properties except for briquette sample 350 μm (90:10) (Figure 8a), which suffer a major crack. This may be due to higher grain size of the PKS in the aggregates, which makes densification difficult compared to others and thus leading to the presence of more internal pores within the briquette. Grain particle sizes also influence the mechanical properties of the briquettes. The finer the particle, the better the cohesiveness and the lighter the crack sustain by the solid fuel. Hence, it is expected that solid fuels in series 150 μm sustains a light crack when compared to either 350 μm or 250 μm. In addition, presence of mesocarp fibers improves the interlocking of briquette aggregates as reported by Chin Yee & Shiraz (2012); Chin Yee & Shiraz (2013). Hence, in relation to the mesocarp fiber proportion, it is evident from Figure 8 that the briquettes in series 150 μm sustain lesser cracks than the other two series which means they are better mechanically. Also, it is

expected that as the percentage mesocarp fiber increases in the briquette, the mechanical properties of the fuel also increase. This also justifies why briquette sample 350 µm (90:10) (Figure 9a) displayed poor mechanical strength and suffer major crack.

**(a) 350 µm 90:10**

**(b) 350 µm 80:20**

**(c) 350 µm 70:30**

**(d) 250 µm 90:10**

**(e) 250 µm 80:20**

**(f) 250 µm 70:30**

**(g) 150 µm 90:10**

**(h) 150 µm 80:20**

**(i) 150 µm 70:30**

Figure 9. Briquettes presentation in their mixing proportion after crack analysis

Table 3. Physical Observations of the Crack Test

| Mixing Ratios | Grain sizes (μm) | Not Bad | Mildly Bad | Very Bad |
|---|---|---|---|---|
| **90PKS:10MF*** | 350 | --- | • | **---** |
| **80PKS:20MF** | 350 | • | --- | --- |
| **70PKS:30MF** | 350 | • | --- | --- |
| **90PKS:10MF** | 250 | • | --- | --- |
| **80PKS:20MF** | 250 | • | --- | --- |
| **70PKS:30MF** | 250 | • | --- | --- |
| **90PKS:10MF** | 150 | • | --- | --- |
| **80PKS:20MF** | 150 | • | --- | --- |
| **70PKS:30MF** | 150 | • | --- | --- |

* PKS:MF = Palm kernel shell:Mesocarp fiber

## 3.2 Combustion Characteristics of the Fuel Samples

Porosity index, ignition time, burning time, burning rate, specific fuel consumption and physical appraisal of the fuel samples during and after combustion are explained in this section. Table 4 gives information on the porosity index, ignition time, burning time to boil water (100 cm3), burning rate and specific fuel consumption of each briquette and accordingly were repeated for the three particle sizes. In addition, there is a direct relationship between porosity and the ignition time. Burning rate was estimated to evaluate the cooking viability of the briquette produced. On the corollary, the fuel that shares a better burning rate will be expected to have a smaller quantity of fuel in boiling water. Figure 9 shows the porosity index of the solid fuels while ignition and water boiling time were indicated respectively in Figures 10 and 11. Figure 12 and Table 5 shows the specific fuel consumption and general assessment of the fuel samples respectively. Smoke, nature of flame and the odour of the fuel briquettes are also noted during burning.

Table 4. Comparing the combustion assessment of biomass solid fuel samples (PKS:MF) in different mixing ratios and particle sizes with other solid fuels and kerosene

| Biomass Solid Fuels | Grain sizes (μm) | Porosity Index | Ignition Time (sec) | Burning Time (min) | Burning Rate (g/min) | Specific Fuel Consumption (g/l) | References |
|---|---|---|---|---|---|---|---|
| **90PKS:10MF*** | 350 | 0.69 | 11.69 | 2.00 | 0.59 | 11.80 | Present study |
| **80PKS:20MF** | 350 | 1.19 | 7.51 | 3.20 | 1.61 | 53.50 | Present study |
| **70PKS:30MF** | 350 | 1.39 | 5.71 | 3.41 | 1.18 | 43.50 | Present study |
| **90PKS:10MF** | 250 | 1.18 | 9.00 | 2.28 | 2.21 | 54.50 | Present study |
| **80PKS:20MF** | 250 | 1.25 | 6.00 | 3.50 | 1.38 | 52.70 | Present study |
| **70PKS:30MF** | 250 | 1.42 | 5.20 | 4.10 | 0.60 | 24.90 | Present study |
| **90PKS:10MF** | 150 | 1.11 | 7.30 | 2.56 | 1.30 | 38.20 | Present study |
| **80PKS:20MF** | 150 | 1.29 | 6.00 | 3.00 | 1.85 | 55.60 | Present study |
| **70PKS:30MF** | 150 | 1.41 | 4.00 | 2.00 | 2.40 | 48.10 | Present study |
| **70Coal: 30Corncob** | --- | 0.37 | 300.00 | 58.00 | --- | --- | (Ilochi, 2010) |
| **70Coal: 30Groundnut shell** | --- | 0.34 | 480.00 | 66.00 | --- | --- | (Ilochi, 2010) |
| **Spear Grass** | --- | 3.520 | 286.00 | --- | --- | --- | (Onuegbu et al., 2010) |
| **Charcoal** | --- | --- | --- | 2.170 | --- | --- | Present study |
| **Kerosene** | --- | --- | --- | 1.570 | --- | --- | Present study |

* PKS:MF = Palm kernel shell: Mesocarp fiber

### 3.2.1 Porosity Index

Figure 10 shows the porosity index of the biomass solid fuels. Aggregate 250 μm (70:30) has the highest porosity index and it was followed by 150 μm (70:30). The porosity index of the fuel samples could be explained based on the percentage mesocarp fiber and grain particle sizes. The figure shows that in each series, the porosity index increases with increase in the percentage mesocarp fiber in the aggregates. This may be due to the nature of the mesocarp fiber. The palm kernel shell grain particles normally interlock within the fibrous mesocarp during densification and allow it form a rigid composite that could resist excess water. The finer grain particles form a better briquette will few pores. The results from the current study were compared with those of coal and corn cob aggregates as well as coal and groundnut shell fuel briquettes produced by Ilochi (2010). The porosity indices of the fuel briquettes produced

here were found to have better characteristics, and thus the briquettes can function very well as a good solid fuel. Onuegbu, Ogbu, Ilochi, Ekpunobi & Ogbuagu (2010) reported 3.520 as the porosity index of 100% biomass material (spear grass) briquette, which is higher than those obtained for briquettes produced with PKS of 250 μm and 350 μm in the current study. Although, low porosity may hinder the combustion property of solid fuels due to fewer pores for mass diffusion (Onuegbu et al., 2010; Davies & Abolude, 2013), but it is not the only determinant of the fuel viability. The high porosity index obtained by Onuegbu et al., (2010) may be due to the nature of the biomass material used. The higher the porosity, the higher the rate of infiltration of oxidant and out flow of combustion/pyrolysis products during combustion and the higher will be the burning rate of the briquette.

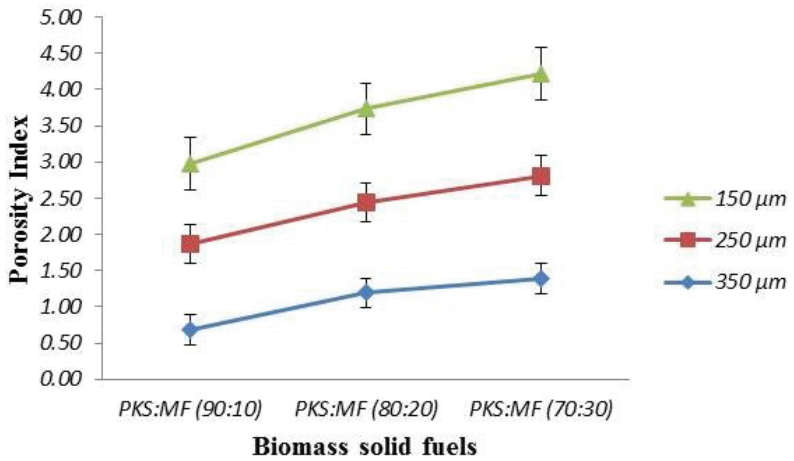


Figure 10. Porosity Index of PKS:MF Solid Fuels at different mixing ratios and particle sizes

### 3.2.2 Ignition Time

Figure 10 shows that briquette samples with 350 μm (90:10) have the highest ignition time, followed 250 μm (90:10) and 350 μm (80:20). At each mixing ratio, there is a reduction in the ignition time of the fuels. However, the rate at which the reductions occur does not follow the same pattern. The high at ignition time of the briquettes could be due to the higher proportion of the palm kernel shell in this series and as well as the large grain particles of the palm kernel shell. That is why at each grain size, the ignition time reduces as the percentage

mesocarp fiber increases. Besides, smaller particle size due to their surface area tends to ignite easily and combust as fast as possible compared to larger particle size. It was reported equally that tha increment in the densification pressure leads to an increment in the ignition time and have a direct relationship with combustion (Davies & Abolude, 2013). Finally, it could be inferred that the ignition time does not only reduce as a result of the grain size of the particles, but also proportional to the densification pressure and percentage mesocarp fiber presented in the aggregates.

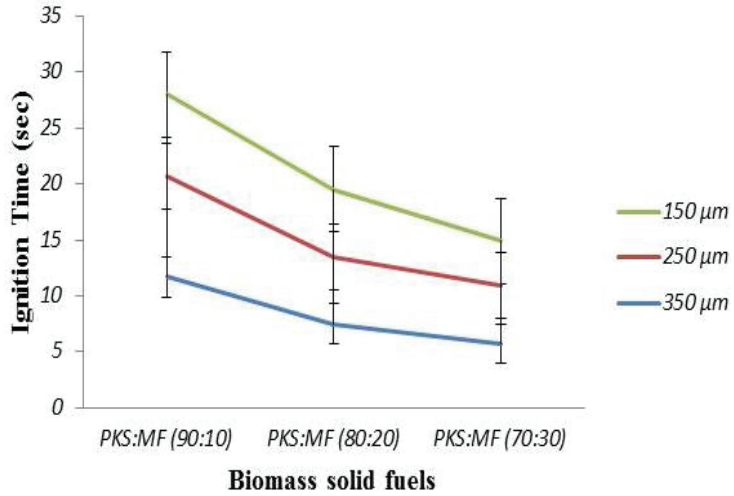


Figure 11. Ignition time of biomass solid fuels at different mixing ratios of PKS:MF and grain sizes

### 3.2.3 Burning Time

The burning time indicates the time taken by water to fully reach the boiling temperature. The highest boiling time of water using fuel briquette aggregate 250 µm grain size in ratio 70:30 is 4 min 1 sec, followed by (250 µm, 80:20) at 3 min 5 sec and (350 µm, 80:20) at 3 min 2 sec as shown in Figure 11. For the whole samples, the water boiling time is between 2 min and 4 min 1 sec. The burning time at mixing ratio of 90% PKS to 10% MF took lesser time in boiling; probably due to the presence of more palm kernel shell and bigger grain particles in the aggregates. It was initially stated that larger particle sizes of any solid fuel due to their porosity are expected to portray good burning

property. Therefore, the boiling time realized at ratio 90 to 10 (PKS:MF) could be due to proper inflow and outflow of air or calorific value of palm kernel shell which allows it to generate a significant energy. There are fluctuations at series 250 μm and 150 μm aggregates, which could perhaps be associated with the boiling water itself.

A number of literature such as Onuegbu et al., (2010) and Davies & Abolude (2013) have indicated that, boiling time decrease with an increase in the biomass materials in the composition of any solid fuel when used to boil equal volume of water. Ilochi (2010) reported the burning time of 7.00 min for boiling 1 litre of water using coal and corn cob at ratio 70 to 30 while Onuegbu et al., (2010) reported 8.00 min for 100 cm3 of water with coal and spear grass at ratio 50 to 50. The high burning time reported by Onuegbu et al., (2010) may be due to the pressure exerted during densification. Moreover, the oil residue in palm kernel shell and mesocarp fiber could partially be responsible for this little time in burning. Furthermore, the present study established that charcoal and kerosene recorded 2 min 17 s and 1 min 57 s, respectively, when they were being used to boil the same volume of water. Fossil fuels (kerosene) due to its high calorific value (11,100 kCal/kg) can combust as fast as possible though contribute a lot to greenhouse gases. Charcoal boiled the water at 2.170 min and will have to compete with 350 μm (90:10) and 150 μm (70:30) with 2.00 min, respectively.

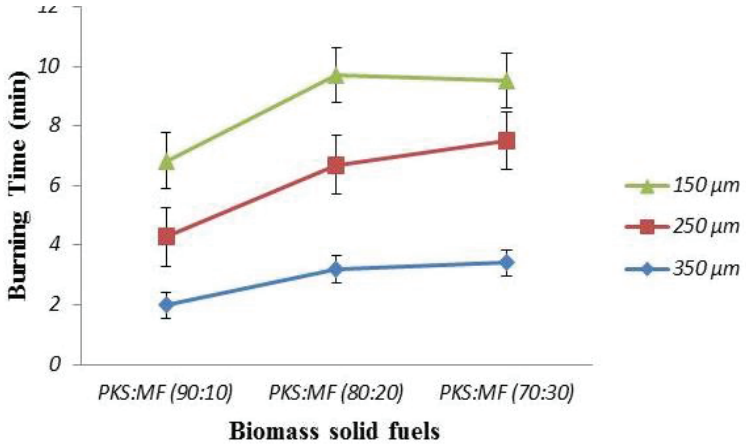


Figure 12. Burning Time of aggregates PKS:MF in their ratios to boil 100 $cm^3$ of water

### 3.2.4 Specific Fuel Consumption and Physical Observations of the Fuels During and after Combustion

The specific fuel consumption of the briquette samples show that the fuel consumption for boiling 100cm$^3$ of water progressively increased as the percentage mesocarp fiber increased in the aggregates. In addition, according to Figure 13, grain particle is also partially responsible for fuel consumption. It is expected that finer particle size of palm kernel shell ignite quickly and boil the water faster especially when volume of the water is small. This is likely the more reason why briquette 150 μm (80:20) specifically consumed higher fuel for boiling of water. Besides, the results obtained respectively for water boiling (burning time) and the burning rate further emphasize how well the cooking efficient of the briquettes are. On the other hand, the physical observation of the briquettes in the course of combustion is shown in Table 5. It could be inferred from the table that, all the three series shows a bluish color and with faint smoke on combustion at ratio 90 to 10 while other ratios in the series indicated yellowish color. It was earlier stated that all the aggregates pass through the same initial treatment, and even with that, it is expected that the palm oil remains in palm kernel shell will be small compared to mesocarp fiber. The palm oil traditionally give more smoke and this could be a reason for the other two ratios with higher proportion of mesocarp fiber to generate more smoke than those at ratios 90 to 10.

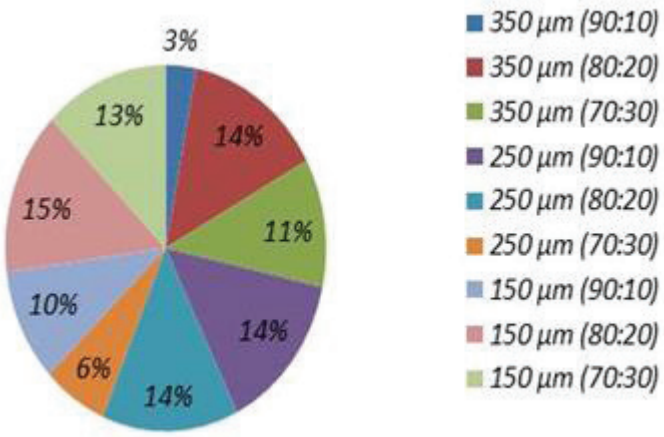


Figure 13. Specific Fuel Consumption of each of the solid fuel samples in their ratios and grain sizes

Table 5. Physical observation of the fuel samples during and after combustion

| Biomass Solid Fuels | Grain sizes (μm) | Smoke | Nature of the flame | Odour | Fuel used for Ignition |
|---|---|---|---|---|---|
| **90PKS:10MF*** | 350 | Burnt with faint smoke | Bluish | No odour | 3 ml |
| **80PKS:20MF** | 350 | Burnt with higher level of smoke | Yellowish | No odour | 3 ml |
| **70PKS:30MF** | 350 | Burnt with higher level of smoke | Yellowish | No odour | 3 ml |
| **90PKS:10MF** | 250 | Burnt with faint smoke | Bluish | No odour | 3 ml |
| **80PKS:20MF** | 250 | Burnt with higher level of smoke | Yellowish | No odour | 3 ml |
| **70PKS:30MF** | 250 | Burnt with higher level of smoke | Yellowish | No odour | 3 ml |
| **90PKS:10MF** | 150 | Burnt with faint smoke | Bluwish | No odour | 3 ml |
| **80PKS:20MF** | 150 | Burnt with higher level of smoke | Yellowish | No odour | 3 ml |
| **70PKS:30MF** | 150 | Burnt with higher level of smoke | Yellowish | No odour | 3 ml |

* PKS:MF = Palm kernel shell: Mesocarp fiber

## 4.0 CONCLUSIONS

The mechanical analysis results showed that solid fuel 350 μm (90:10), followed by 350 μm (80:20) possesses the least durability while solid fuel 350 μm (90:10) suffered a major crack during the crack test. The water resistance test of the fuel samples showed that fuel sample 350 μm (90:10) recorded the least duration (15 min 40 sec) while 23 min 40 sec was the highest time by series 150 μm (70:30). The combustion assessment revealed that briquette 350 μm (90:10) has the best porosity index of 0.69 while series 250 μm (70:30) has the least (1.42). The ignition time showed that 150 μm and 250 μm in their ratios have a good ignition rate except for their ratios 90:10. Burning time of the fuels showed that solid fuel with series 350 μm (90:10) and 150 μm (70:30) are the best, followed by fuel sample 250 μm (90:10). Based on this results, any one of these fuel samples can be recommended as good biomass solid fuel for either domestic or industrial purposes. Therefore, the oil-palm waste based solid fuels are viable alternative energy source and also an alternative way to manage the wastes.

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