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DISCOVERY

Production of briquettes with heating value using different palm kernel shell

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Investigation was carried to study the variability and performance of briquettes produced from palm kernel shell (PKS), obtained from three locations using cassava starch as binder. Effects of compression pressure and binder content were studied as performance measures to improving the efficiency of briquette. Analysis showed that moisture content decreased with increase in compression pressure, while the reverse was the case for ash content of PKS briquettes. However, the density, moisture content, ash content, volatile matters and fixed carbon of the briquettes obtained at 70kN/m^2 and 8.57% binder content were 1.23g/cm^3, 3.8%, 3.76%, 73.01% and 23.38% in briquette AB, 1.27g/cm^3, 3.5%, 3.78%, 74.26% and 21.96% in briquette RB and 1.28g/cm^3, 3.1%, 3.82%, 76.60% and 19.58% in briquette EB respectively. Also, the ignition time, water boiling time, calorific value and thermal efficiency increased as compression pressure and binder content were increased, while mass of briquettes consumed, burning rate and specific fuel consumption decreased with increase in compression pressure and binder content. The optimum performance was recorded at 8.57% binder content and 70kN/m^2 compression pressure, with burning rate, specific fuel calorific value and thermal efficiency obtained as 0.49g/min, 0.0150 kg fuel/L, 20058.17 kJ/kg and 49.44% in briquette AB, 0.46g/min, 0.0146 kg fuel/L, 20629.46 kJ/kg and 50.14% in briquette RB and 0.43g/min, 0.0142 kg fuel/L, 21246.17 kJ/kg and 50.45% in briquette EB respectively. However, briquette EB performed slightly better than briquettes RB and AB. Also, mathematical relationship established between temperature rise and time as well as the amount of briquette consumed with time during combustion process, can be described by quadratic function. Summarily, the high calorific value, thermal efficiency and the low burning rate of PKS briquettes amongst other excellent properties, are potential indicators that proper utilization of PKS for briquetting in Nigeria would contribute to solving the existing energy crisis, which would reduce the over dependence on refined petroleum products for domestic and commercial heating.

INTRODUCTION

Nigeria is blessed with lots of energy sources, ranging from water resources, fossil fuels to agro wastes. Although, in spite of the availability of these energy sources, there are still challenging issues in finding appropriate ways of harnessing and converting them to useful energy output. One continue to wonder why Nigeria still focus only on convectional fuel as the main source of energy generation, while other sources of energy remained untapped.

This over dependent on convectional fuel for energy supply in the country is believed to have contributed to the energy crisis experienced over time in the country, ranging from poor power supply to shortage and sudden hike in price of petroleum products (Akuma and Charles, 2017). However, one of the ways of addressing this menace is to harness the numerous available fuel resources by make a useful energy output (Abdulrasheed *et al*., 2015). Even more interesting, most of these energy sources are often regarded as waste with no secondary value, thereby, disposing them is the only resort (Adeniyi *et al*., 2014).

Indeed, agriculture remains the main occupation of most Nigerians, which involves a lot of activities, and these activities generate so many wastes that are disposed ignorantly. It has been found that these wastes can be re-integrated to contribute in solving the energy problem of Nigeria as a nation (Ogbuanya, 2005; Adeniyi *et al*., 2014). In most Nigerian rural communities, forest resources are the predominant fuel source. The trees are felled, allowed to dry and the different parts of the dried plants are used as firewood (Adeniyi *et al*., 2014; Akuma and Charles, 2017). Another way that people use to generate heat and light is by the conversion of wood to charcoal. Other plants, apart from trees, are also used as fuel sources (Oyelaran *et al*., 2015; Onukak *et al*., 2017). The problem of tree cutting primarily as fuel source has great negative impacts on the environment. However, this can be limited if only the naturally dead part and other agro wastes are converted into briquettes, which will go a long way to preventing deforestation thereby protecting the environment (Adeniyi *et al*., 2014).

Briquetting is a process of binding together pulverized carbonaceous matter, often with aid of binder (Martin, *et al*., 2008; Murthy *et al.* 2017). The common forms of briquettes are the coal briquettes and the biomass briquettes. Biomass briquettes originate from mostly agricultural remnants or residues. These include the charcoal briquettes. In this research, the plant of interest is the oil palm plant. The Oil Palm plant (*ElaisGuinensis*) produces a fruit with nut inside the fruit. The fruit is boiled in water to extract the palm oil. After the oil extraction from the fruit, the nuts are broken for the palm kernels. The broken shells are

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called Palm Kernel Shells (PKS). The palm oil plants are found in most parts, especially, southern states of Nigeria. The different parts of the oil palm are adapted for different useful purposes (Ukpaka Chukwuemeka Peter and Okochi Godspower Ikechukwu, 2018; Olukanni *et al*. 2019). While the leaves provide brooms for sweeping the environment, the kernel is a major source of red palm oil used for cooking. The seed is the source of palm kernel oil (PKO) used extensively in the pharmaceutical and cosmetic industries. In the palm oil processing operations, the solid wastes are the empty fruit bunches, palm fiber, and palm kernel shell (Ugwu and Agbo, 2011).

In rural community settings, palm kernel shells are used for heating during cooking in the form of crude, however, it burns with a lot of smoke due to its organic content property. The effect of such smoke is hazardous to health. Even in such cases most of the energy content is not used up as palm kernel shell charcoals (incomplete burnt palm kernel shells) are common sight at ash dumps. Carbonizing and briquetting would remove these for efficient and sustainable use of palm kernel shell. This research is to harness the efficient and effective application of palm kernel shell to make a contribution to the energy domain. With the increased activity of energy utilization in the world and the encouragement of renewable energy for sustainability from biomass, a direct look has been in our natural resources that may seem a waste in our environment. Literatures as well as scientists has speculated the characteristics of palm kernel shell as one with a high hydrocarbon content and has the potentiality of being able to harness out energy from the shells.

The aim of this research is to investigate the effect of compression pressure and binder concentration on briquettes produced from palm kernel shell using the calorific value as the primary parameter to determine the performance.

MATERIALS AND METHODS

This chapter involves the methodology adopted in achieving the stated objectives of this study. The materials used, as well as the procedures taking to arriving at the indented results have been documented in sequences as the analyses were carried out.

Materials

The materials used in the experiment for making of briquettes are listed as follows: Palm kernel shell, cassava starch, knife, sack cloth, metal sheets, oven, crusher, weighing balance, hydraulic pressing machine, air dryer, sieve, mould, crucible, kerosene, cooking stove, lighter, thermometer, cooking pot, measuring cylinder, beaker, stirrer and water

Methods

The making of briquettes involved several stages, which include: sample collection, preparation, formulation of the briquettes, test analysis and energy evaluation.

Collection of Samples

Palm kernel shells were collected from three locations in the South-South Geopolitical Zone of Nigeria. They are Osisioma palm oil mill in Osisioma Local Government Area of Abia State, Agenebode palm oil mill in Ishan Local Government Area of Edo State and Okposi palm oil mill in Ogba/Egbema/Ndoni Local Government Area of Rivers State. The cassava tubers were collected from cassava farm cultivated by my family in Okposi Community, Ogba/Egbema/Ndoni Local Government Area of Rivers State.

Preparation of Palm Kernel Shell

After obtaining the palm kernel shells (PKS) from the locations, they were transported to the laboratory for preparation and analysis. Firstly, the PKS were washed thoroughly with water to remove unwanted materials such as sand and plant leaves, which could alter the properties of the briquette. The washed PKS were spread out on a mat and sun dried daily for two weeks, in order to reduce moisture content. The dried PKS were crushed in accordance with the technique described by Ugwu and Agbo (2011). Thus, a measured volume of about 15ml of kerosene was sprinkled on the dried PKS and transferred into metal container that was perforated underneath. Heat is then applied through the bottom of container to carbonize the PKS. It is worthy of note that the sprinkling of kerosene was to facilitate ignition of the PKS during the heating process for carbonization. On heating, the shells ignited for few minutes with initial yellow flame, which changed to blue. The heating was continued for about 8 hours and the container brought down from the support while still air-tight to prevent entry of air. The carbonized PKS did not form ash deposit after cooling. The carbonized PKS crushed to fine powered particles using electric blender. The crushed particles were transferred to standard sieve of mesh size of 2mm to obtain a uniform particle sizes.

Preparation of Binder

Cassava starch was used as binder, and it was extracted from the cassava tuber. The cassava tubers were washed and then peeled manually with knife. The peeled tubers of cassava were crushed to slurry form using cassava crushing machine. The crushed cassava was carefully transferred into sack cloth and placed in between two metal sheets, and then compressed vigorously to extract the liquid content, which was received by a bigger container where it was allowed to settle for about 12 hours. Thereafter, the clear liquid was carefully decanted off and the starch residue was sun dried for at least 7 days to remove moisture content.

Briquette Formation

The dried cassava starch was weighed to different weights of 25g, 50g, 75g and 100g and transferred into containers. This was done to study the effect of binder concentration on the performance of PKS briquette. A measured volume of water was added into the containers accordingly (i.e. 50ml in 25g container, 100ml in 50g container, 150ml in 75g container and 200ml in 100g container respectively), and then stirred vigorously to dissolved the starch. For purpose of easy identification, samples in the containers were labeled S_{25}, S_{50}, S_{75} and S_{100}. Once at a time, 200ml, 400ml, 600ml and 800ml of water respectively, were added into heating vessel, and then heated until itboils. The corresponding prepared samples: S_{25}, S_{50}, S_{75} and S_{100} were added into the boiling water. The content was again stirred to obtain starch gel. In each mix, 800g of the carbonized PKS was slowly added into the gel and stirred until a thick substance was formed. The thick substance was poured into cylindrical moulds and compressed using hydraulic press machine controlled at low compression pressures of 50, 55, 60, 65 and 70kN/m^2. After obtaining the briquettes, it was air-dried and further exposed to the sun further drying for four days (Ugwu and Agbo, 2011). It is worthy of note that compression pressure was only monitored at only sample S_{75}. Similarly, the effect of binder concentration was studied at only 70kN/m^2 compression pressure.

Physical Properties of PKS Briquettes

The physical properties of PKS investigated include density, moisture content, ash Content, volatile matter and the fixed carbon of the carbonized PKS.

Briquette Density

To calculate the density of the briquette, the method described in Tembe *et al*. (2014) was used. Thus, three briquettes were selected at random, and the mass as well as the volume of each of the selected briquette determined. The mass or weight of briquette was determined using digital weighing balance. To determine the volume of briquette, an empty, cleaned plastic plate was placed on a weighing balance to determine its weight. Thereafter, each of the briquettes was put in the plate, and then lowered gently into a water filled 1000ml graduated cylinder, whose initial water level had been recorded. The liquid is allowed to settle and the new level of water recorded. The rise in volume was then recorded as the volume of the briquette. The average weight and volume of the three briquettes were calculated and utilized in the given formula.

$$\rho_b = \frac{W_b}{V_b} \qquad (1)$$

Where, $\rho_b =$ Briquette density (g/cm^3), $W_b =$ Weight of briquette (g), $V_b =$ Volume of briquette (cm^3)

Ash Content

The ash content was determined according to the method described in Onukak *et al*. (2017). Thus, in determination of percentage ash, a constant weight of the compressed briquette sample was heated to 450 ºC for 1 hour, and then cooled before weighing. However, to study the effect of compression pressure on ash content, the processes carried out above was repeated on all the representative samples. The percentage of ash content was calculated using the formula:

$$AC = \frac{W_{dry}}{W_b} \times 100\% \qquad (2)$$

Where, $AC =$ Ash content (%), $W_b =$ Initial weight of briquette (g), $W_{dry} =$ Weight of briquette at 450 ºC (g)

Moisture Content

Like the ash content, the percentage moisture content (MC) was determined according to Onukak *et al*. (2017) method. A constant weight of the crushed briquette sample was oven dried at 105 ºC until a constant weight was obtained. The effect of compression pressure on moisture content was studied by weighing all representative samples of briquettes after compression before subjecting them to combustion test. The percentage of moisture content was calculated using the formula:

$$MC = \frac{W_b - W_1}{W_1} \times 100\% \qquad (3)$$

Where, $MC =$ Moisture content (%), $W_b =$ Initial weight of briquette (kg), $W_1 =$ Weight of briquette at 105 ºC (kg)

Volatile Matter

Percentage volatile matter (VM) was determined using the standard method described by Onukak *et al*. (2017). A constant weight of the crushed briquette sample was dried at 105 ºC until a constant weight was obtained. The sample was then heated further to temperature of 550 ºC for 10min and then cooled before weighing. The percentage of volatile matter was calculated using the formula:

$$VM = \frac{W_1 - W_2}{W_1} \times 100\% \qquad (4)$$

Where, $VM =$ Volatile matters (%), $W_1 =$ Weight of briquette at 105 ºC (kg), $W_2 =$ Weight of briquette at 550 ºC (kg)

Fixed Carbon

The fixed carbon was calculated by subtracting the sum of volatile matter and ash content from 100. This is calculated using the formula (Tembe *et al*., 2014):

$$FC(\%) = 100 - (AC + VM) \qquad (5)$$

Performance Analysis of PKS Briquettes

The performance of the palm kernel shell briquette was determined through combustion analysis and heating value. For comprehensive understanding, the following parameters are determined through the understated formulas.

Ignition Test

This referred to the time taken for the briquette to ignite. About 2-3ml of kerosene was spiked on the briquette and made to burn with aid of lighter. On lighting, the briquette burnt with a smoky yellow flame, which disappeared with time, after the briquette had ignited to a red hot substance that burn with no smoke. The time at which the ignition was observed was recorded using stop watch.

Combustion Test

750ml of water at 28.3ºC (room temperature) was poured into cooking pot and covered with a lid that was perforated so that a thermometer was inserted to measure the rising water temperature. The produced briquette samples were then placed on cooking stove and ignited. The pot with the water content was placed on the stove after ignition. With the aid of stop watch, the time at which the water boils was recorded. This was repeated in all the invested compression pressures and binder concentrations. Also, the mass of briquette before and after water had boiled were recorded, and the following parameters calculated: specific fuel consumption, briquette burning rate heating value, calorific value and thermal efficiency. Further, to study the behavior or profile of briquette mass consumed during the heating, another set of test was performed, where at every 5 minutes, the heating was stopped, the briquette allowed to cool and then weighed to determined the mass lost during the given time. At the same time, the temperature rise of water was recorded.

Briquette Burning Rate

The briquette burning rate was calculated according to the method described in Ugwu and Agbo (2011). This is expressed as the ratio of briquette fuel utilized at boiling point of water to the time taken for water to boil. It is expressed according to the formula:

$$m_b = \frac{m_i - m_f}{t} \qquad (6)$$

Where, $m_b =$ Mass of briquette fuel utilize at boiling point (g), $m_i =$ Initial mass of briquette fuel (g), $m_f =$ Final mass of briquette fuel at boiling point (g), $t =$ Time at which water boils (min)

Specific Fuel Consumption

The specific fuel consumption denotes the amount of briquette that is burnt off or utilized as fuel in generating heat energy when a given volume or weight of liquid, in this case, water is heated to a certain temperature. In this work, volume of water was used instead of weight. Thus, the specific fuel consumption is the ratio of briquette fuel utilized at boiling point of water to the volume of water used for the heating. It is expressed according to the formula:

$$SFC = \frac{m_b}{V_w} \qquad (7)$$

Where, $SFC =$ Specific fuel consumption (kg of fuel/ L of water), $m_b =$ Mass of briquette fuel utilize at boiling point (kg), $V_w =$ Volume of water in the pot (L)

Calorific Value

The calorific value explained how much thermal energy is involved in combustion of one kilogram weight of briquette. It can also be expressed as the amount of briquette required to raise the temperature of a given weight of water. In some studies, the reported calorific value of briquette was measured directly through the bomb calorimeter (Ugwu and Agbo, 2011 and Adeniyi *et al*., 2015), but in absence of the bomb calorimeter, it can be estimated through mathematical correlations. Therefore in this study, the calorific value of PKS briquette was expressed according to Oyelaran *et al*. (2015a), which is the the ratio of sensible heat to the amount of briquette utilized as fuel. Thus, the sensible heat can be determined from the formula:

$$Q_s = m_w C_p (T_f - T_o) \qquad (8)$$

Thus, by definition, the calorific value of PKS briquette was calculated using the relation:

$$CV = \frac{Q_s}{m_b} = \frac{m_w C_p (T_f - T_o)}{m_b} \qquad (9)$$

Where, $Q_s =$ Sensible heat (kJ), $CV =$ Calorific value (kJ/kg), $T_b =$ Temperature of water at boiling point (ºC), $T_o =$ Initial temperature of water (ºC), $m_b =$ Mass of briquette fuel utilize at boiling point (g), $m_w =$ Mass of water in the pot (g), $C_p =$ Specific heat capacity of water (4.2 kJ/kg ºC)

Thermal Efficiency

Wherever there is heating, energy is released in the form of heat through thermo-chemical process. Therefore, when this occurs, the net heat supplied to the system and the total heat released from the system can be evaluated. Hence, in combustion process of briquettes, the net heat supplied to the water is the sum of the heat gained by the water and the amount of water that has evaporated during the heating process, whereas, the total heat released from the system denotes the heat liberated by the briquette in raising the temperature of water up to boiling point. Therefore, thermal efficiency is the ratio of the net heat supplied to the total heat released during the combustion of briquette. This is calculated using the formula described in the work of Adeniyi *et al*. (2014).

$$\eta = \frac{m_w C_p (T_b - T_o) + m_e \ell}{m_b CV} \qquad (10)$$

Where, $\eta =$ Thermal efficiency (%), $m_w =$ Mass of water (kg), $C_p =$ Specific heat capacity of water (4.2 kJ/kg ºC), $T_b =$ Temperature of water at boiling point (ºC), $T_o =$ Initial temperature of water (ºC), $m_e =$ Mass of water evaporated after boiling (kg), $\ell =$ Latent heat of vaporization of water (220kJ/kg), $m_b =$ Mass of briquette used as fuel (kg), $CV =$ Calorific value of briquette (kJ/kg)

RESULTS AND DISCUSSION

Briquettes from palm kernel shell (PKS) obtained from Abia, Edo and Rivers States have been produced and their performance under various controlling parameters equally studied. Besides comparing the performance of the PKS obtained from different locations, the effects of compression pressure and binder content on the briquettes were studied and the results presented and discussed in this chapter.

Table 1 Proximate analysis of PKS Briquettes

Parameter	AB	RB	EB
Density (g/cm^3)	1.23	1.27	1.28
Moisture Content (%)	3.8	3.5	3.1
Ash Content (%)	3.76	3.78	3.82
Volatile Matter (%)	73.01	74.26	76.6
Fixed Carbon (%)	23.38	21.96	19.58

Proximate Analysis of PKS Briquettes

Proximate analysis was carried out on the briquettes after compressing the briquettes. In ash and moisture contents, the analysis was carried out in all the representative samples of the briquettes compressed at pressure of 50 to 70kN/m^2 and binder content of 8.57%, while the volatile matter, fixed carbon and density were performed at only 70kN/m^2. The results are presented in Table 1.

The proximate analysis on the briquettes sample showed that the densities agreed with PKS briquette density of 1.27g/cm^3 reported by

Adeniyi *et al*. (2014), but were greater than 0.91g/cm^3 obtained from palm branch using Maida flour starch (Kumar et al., 2016). They are also greater than 0.524g/cm^3 obtained from mixture of PKS and rice bran with cassava starch as binder (Olugbade and Mohammed, 2015). However, they are less than 1.65g/cm^3 reported by Ugwu and Agbo (2011) with cassava starch binder. In Food and Agriculture Organization manual, 0.90 to 1.30g/cm^3 were specified for briquette density (FAO, 2014).

Effect of Compression Pressure on Briquettes Performance

Briquette materials in its natural state are loose are therefore, required to be compacted, but the level of compaction can influence the overall performance (Demirbas and Sahin, 2001). The compression pressure also improves the strength and durability of the briquette (Onuegbu *et al*., 2010 and 2011). Therefore, effect of compression pressure on the performance of the produced briquettes was investigated.

Moisture content is one of the influential performance indicators in the making of briquette. Figure 1 shows the variation of moisture content of the briquettes at different compression pressure. Increase in compression pressure affects the briquettes by decreasing its moisture content. In comparison, the briquette labeled AB (briquette produced from Abia State PKS) retained more moisture in it than briquette labeled RB and EB (i.e. briquettes produced from Rivers and Edo States PKS). However, the decreases in moisture content at compression pressure of 50 - 70 KN/m^2 were 7.2 – 3.8%, 6.8 – 3.5% and 6.3 – 3.1% for AB, RB and EB briquettes respectively.

Like moisture content, ash content in the briquettes was investigated at different compression pressures to monitor the performance of the PKS briquettes under the influence of compression pressure as shown in Figure 2. Thus, increase in compression pressure slightly increases the ash content in the briquettes, but in comparison, briquette EB has the highest ash content followed by briquette RB and least in briquette AB. Again, as compression pressure was increased from 50kN/m^2 to 70kN/m^2, the ash content increased from 3.49 – 3.76% in briquette AB, 3.51 - 3.78% in briquette RB and 3.56 – 3.82% in briquette EB. However, in Singh and Aris (2013), the ash content obtained from constant PKS briquettes compressed at 200kN/m^2 pressure was 2.82%, while 6.03% ash content was obtained from palm fibre briquettes. Also, in Adeniyi *et al*. (2014), the ash content obtained from manually compressed PKS briquettes was reported between 2.44 - 6.50% at different resident times.

Effect of compression pressure on the ignition time of the briquettes is shown in Figure 3. The ignition time is one of the indicators in determining the performance of briquette. Of carouse, as it were in the proximate analysis, different material exhibits distinct range of values. In Figure 3, it can be seen that compression pressure has significant influence on the time of briquette ignition. Thus, increase in compression pressure increases ignition time of the briquettes. This increase elongation in time of briquette ignition at higher compression pressure can be attributed to closure of pore spaces due compaction.

The time at which briquette fuel releases the heat needed to boil a given mass of liquid is another factor required to test the economic viability of briquettes. Thus, the boiling time of water was investigated at different compression pressures as shown in Figure 4. Like ignition time, increase in compression pressure also increases the boiling time of water as a result of high compaction of the briquettes. Thus, as compression pressure was increased from 50kN/m^2 to 70kN/m^2, boiling time of briquettes increased from 17.23 - 23.15 minutes in briquette AB, 18.15 - 24.05 minutes in briquette RB and 18.57 - 24.49 minutes in briquette EB. Here, it took briquette EB longer time to boil 750ml of water than briquettes RB and AB. It should be noted that the time characteristics of the briquettes recorded for the ignition time is the same as for the boiling time. This could be that briquette AB contains more volatile substance, which increases the combustion rate than briquettes RB and EB.

The mass of briquette converted to fuel (consumed) during the heating of water to its boiling point was also measured as one of the ultimate test analysis to determine the economic usefulness of the briquettes. The profiles of the briquette mass consumed during the combustion test at different compression pressures are shown in Figure 5. Increase in compression pressure amounted to decrease in the mass of briquettes consumed. Thus, as compression pressure was increased from 50kN/m^2 to 70kN/m^2, the mass of briquettes consumed decreased from 12.82 - 11.26g in briquette AB, 12.45 - 10.95g in briquette RB and 11.91 - 10.63g in briquette EB. It is seen that the mass of briquette AB converted to fuel at boiling point of water was higher than those of briquettes RB and EB.

The burning rate of PKS briquette was studied at different compression pressures as shown in Figure 6. The burning rate of briquette is another ultimate test indicator that helps to ascertain the performance of briquette. In this study, increase in compression pressure decreased the burning rate of PKS briquettes. This is due to high compaction, which closes up the pores in the briquettes thereby, limiting the percolation of oxygen required to increase burning rate (Onuegbu *et al*., 2011 and Abdulrasheed *et al*., 2015). From the investigation, as compression pressure was increased from 50kN/m^2 to 70kN/m^2, the burning rate of PKS briquettes decreased from 0.74 - 0.49g/min in briquette AB, 0.69 - 0.46g/min in briquette RB and 0.64 - 0.43g/min in briquette EB. Again, briquette AB has the highest rate of burning, and hence, lost more weight per time during the heating process than briquettes RB and EB, hence, the highest burning rate.

The specific fuel consumption of PKS briquette studied at different compression pressures is shown in Figure 7. The specific fuel consumption of PKS briquette decreases as compression pressure was increased. Thus, as compression pressure was increased from 50kN/m^2 to 70kN/m^2, the specific fuel consumption of PKS briquette decreased from 0.0171 - 0.0150kg fuel/L water in briquette AB, 0.0166 - 0.0146kg fuel/L water in briquette RB and 0.0159 - 0.0142kg fuel/L water in briquette EB. That is, at 50kN/m^2, 0.0171kg, 0.0166kg and 0.0159kg of briquettes AB, RB and EB respectively, would be consumed to boil 1 litre of water, which again indicated that briquette AB was more consumed than briquettes RB and EB to boil the volume of water.

Calorific value is one of the most important indicators for determining the performance of briquette. The effect of compression pressure on calorific value of PKS briquette is shown in Figure 8. Increase in compression pressure simultaneously increased the calorific value of PKS briquettes. Thus, from 50kN/m^2 to 70kN/m^2 compression pressure, the calorific value increased from 17619.04 - 20058.17kJ/kg in briquette AB, 18142.74 - 20629.46kJ/kg in briquette RB and 18958.90 - 21246.17kJ/kg in briquette EB. Again, the calorific value in briquette EB was higher than those of briquettes RB and AB. This implied that briquette EB generated more heat required to change the state of water from liquid to vapour than briquettes RB and AB at the same kilogram, thereby making the water to boil at lesser time.

Another measuring parameter used in determining the quality of briquettes is the thermal efficiency. This is the ratio of the heat absorbed by the heated liquid (water) to the heat supplied by the briquette. It can equally be interpreted as the conversion ability of the briquette fuel into

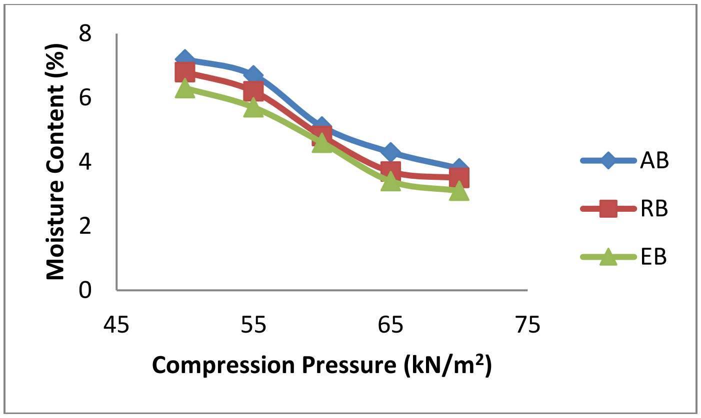

Figure 1 Effect of Compression Pressure on Moisture Content

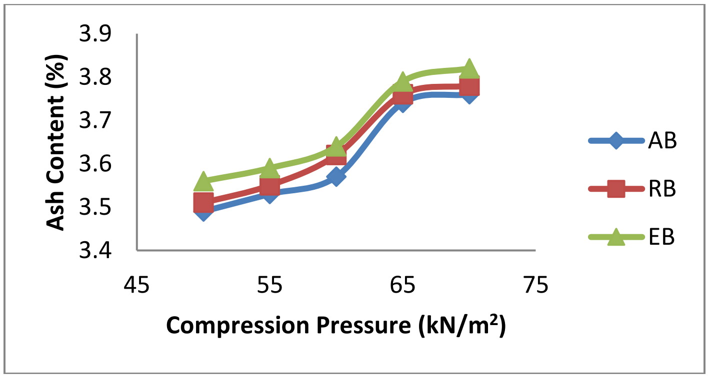

Figure 2 Effect of Compression Pressure on Ash Content

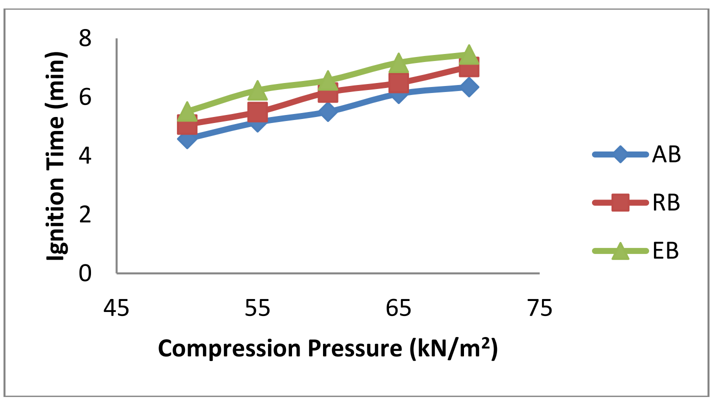

Figure 3 Effect of Compression Pressure on Ignition Time of Briquettes

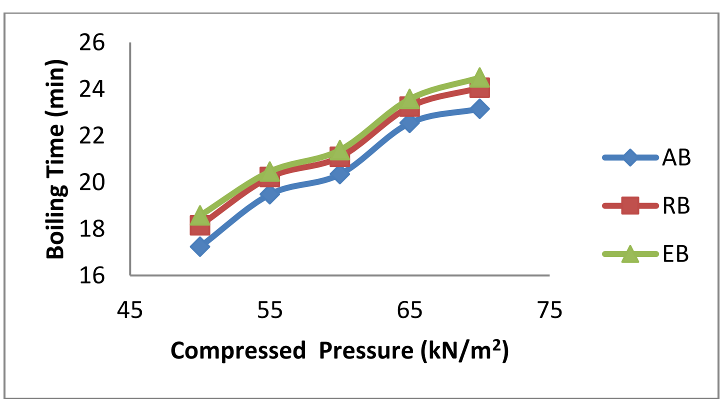

Figure 4 Effect of Compression Pressure on Boiling Time of Liquid

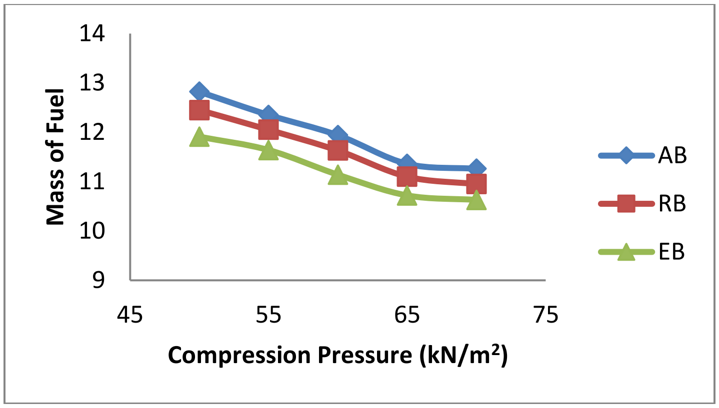

Figure 5 Effect of Compression Pressure on Briquettes Fuel

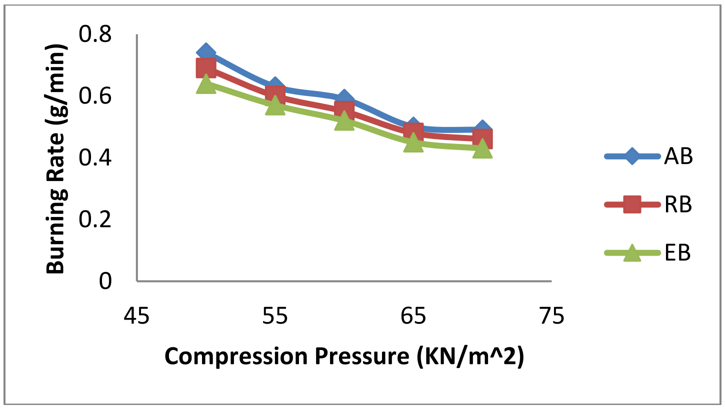

Figure 6 Effect of Compression Pressure on PKS Briquettes Burning Rate

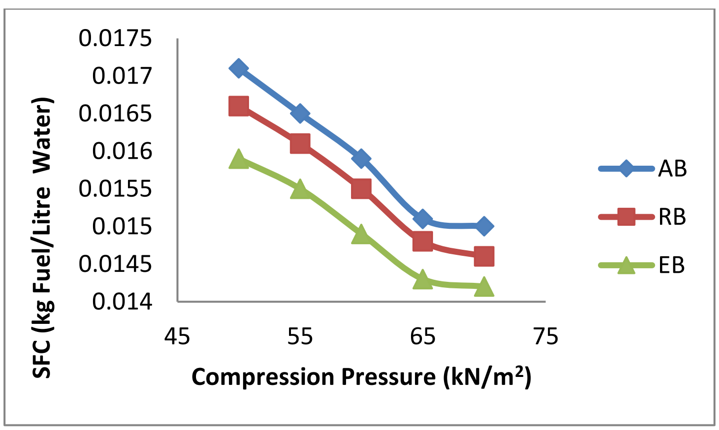

Figure 7 Effect of Compression Pressure on Specific Fuel Consumption

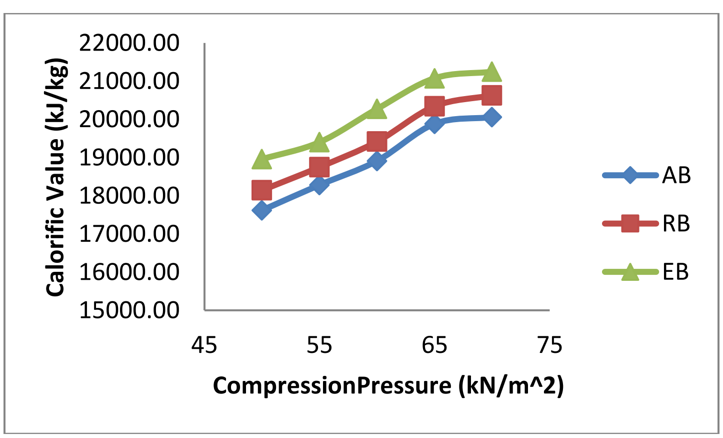

Figure 8 Effect of Compression Pressure on the Sensible Heat Value

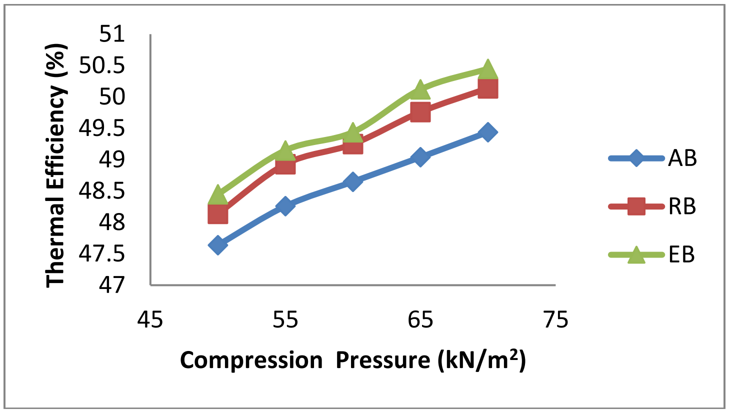

Figure 9 Effect of Compression Pressure on Thermal Efficiency

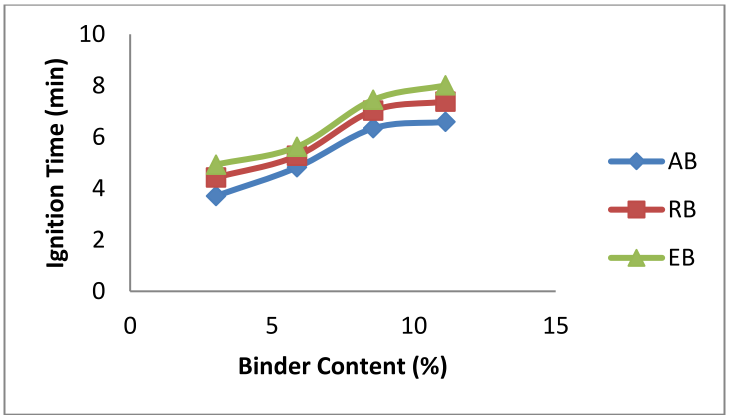

Figure 10 Effect of Binder Content on Ignition Time

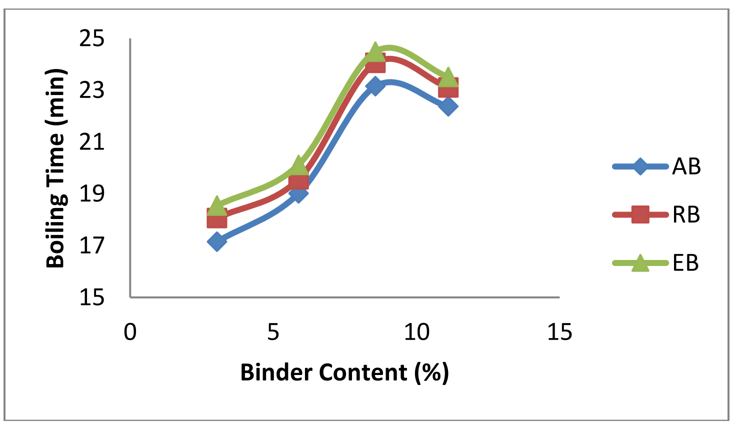

Figure 11 Effect of Binder Content on Boiling Time

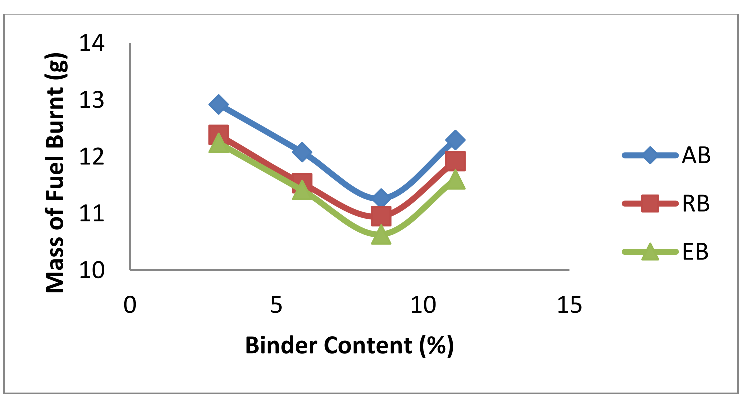

Figure 12 Effect of Binder Content on Briquettes Fuel

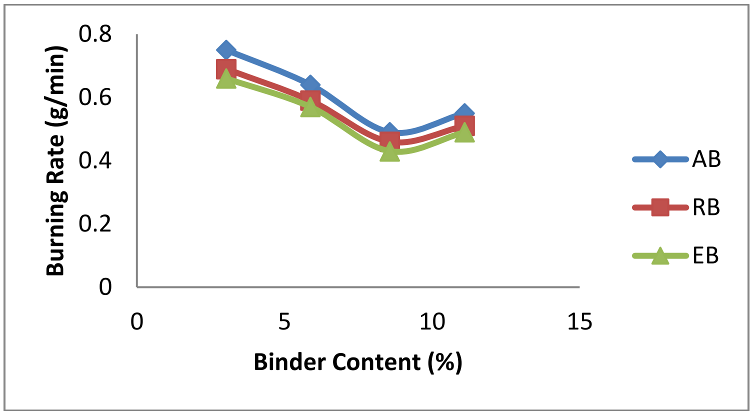

Figure 13 Effect of Binder Content on Briquettes Burning Rate

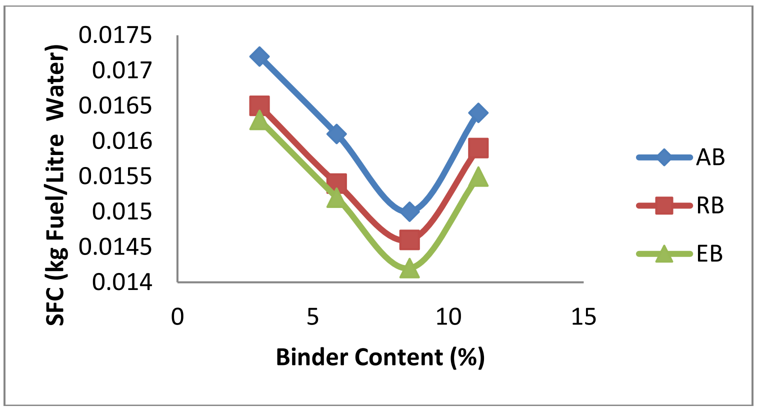

Figure 14 Effect of Binder Content on Specific Fuel Consumption

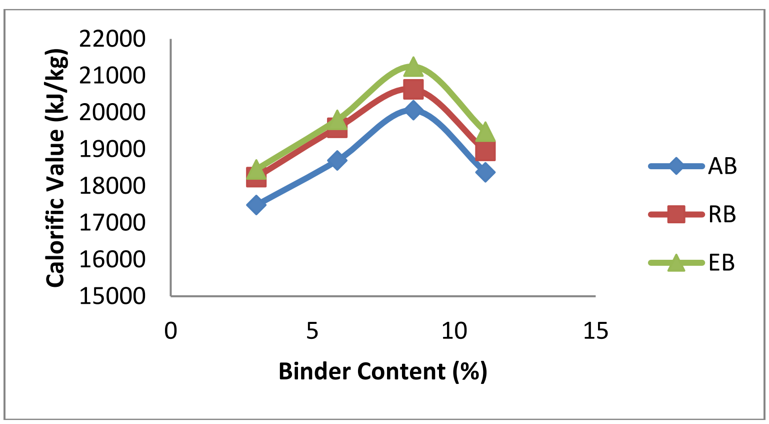

Figure 15 Effect of Binder Content on Calorific Value

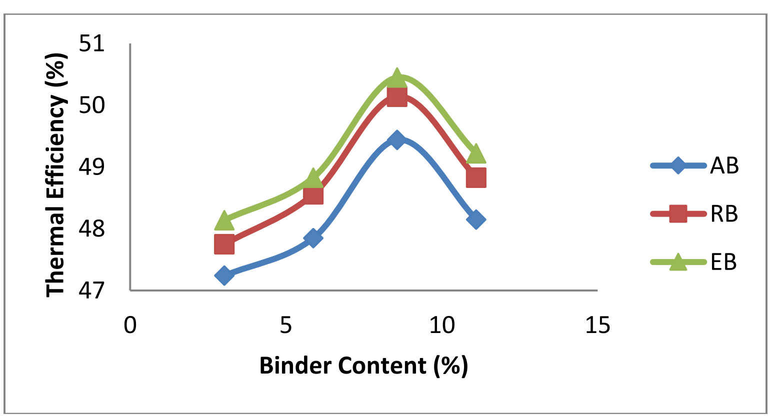

Figure 16 Effect of Binder Content on Thermal Efficiency

heat energy (Onukak *et al*., 2017). The variation of thermal efficiency of PKS briquette subjected to different compression pressures is shown in Figure 9. Again, increase in compression pressure increases the PKS briquettes thermal efficiency. Thus, when compression pressure was increased from 50kN/m^2 to 70kN/m^2, the thermal efficiency increased from 47.64 - 49.44% in briquette AB, 48.14 - 50.14% in briquette RB and 48.45 - 50.45% in briquette EB.

Effect of Binder Content on Briquettes Performance

The influence of binder content on the performance of briquette was studied at constant compression pressure of 70kN/m^2. As had been reported, briquettes produced with different binder species have different characteristics, which strongly is affected by the raw material properties and binder concentrations (Gbabo *et al*., 2018). Besides functioning as binding agent, binder addition in biomass, also improves the quality and strength of briquettes (Bazargan *et al*., 2017). Therefore, effect of cassava starch (binder) content on the PKS briquettes performance was investigated.

Effect of cassava starch binder on ignition time of the briquettes was investigated as shown in Figure 10. Increase in binder content in the briquette increased the ignition time. Thus, as binder content was increased from 3.03 to 11.11%, the ignition time of briquettes increased from 4.01 - 6.59 minutes in briquette AB, 4.48 - 7.38 minutes in briquette RB and 5.03 - 8.01 minutes in briquette EB. Briquette EB takes longer time to ignite than briquettes RB and AB.

Effect of binder on boiling time of water was studied and shown in Figure 11. Again, increase in binder content in the briquette affected the time at which water boils. Initially, increase in binder content from 3.03 to 8.57% increases the boiling time, but declined as the binder content was increased to 11.11%. The boiling time of briquettes at binder content of 3.03 - 8.57% and 11.11% are 17.15 - 23.15 min and 22.37 min in briquette AB, 18.06 - 24.05 min and 23.11 min in briquette RB and 18.54 - 24.49 min and 23.51 min in briquette EB. Again, briquette EB takes longer time to boil 750ml of water than briquettes RB and AB.

Effect of binder on the mass of briquette consumed during the boiling of water was studied as shown in Figure 12. Initially, increase in binder content from 3.03 to 8.57% decreases the mass of briquette consumed, but increased as the binder content was increased to 11.11%. Thus, the mass of burnt briquettes during the boiling of water at binder content of 3.03 - 8.57% and 11.11% are 12.92 - 11.26g and 12.29g in briquette AB, 12.38 - 10.95g and 11.92g in briquette RB and 12.24 - 10.63g and 11.60g in briquette EB. Although, the differences in fuel utilized by the various briquettes were not very far apart, the mass of briquette converted into fuel to boil 750ml of water was lower in briquette EB than in briquettes RB and AB.

It is worthy of note that the optimum briquette performance was recorded at binder content of 8.57%. Naturally, it is expected that the mass of briquette should decrease further at binder content of 11.11%, but this was not the case. The scenario can be attributed to compaction level, which has made the starch to seal up existing pores in the briquettes, and binder content beyond 8.57% in the briquette may have increased volatility hence, the further increase in the mass of briquette consumed.

Similarly, effect of binder content on briquette burning rate was studied as shown in Figure 13. Again, increase in binder content from 3.03 to 8.57% decreases the burning rate of briquette fuel, but increased thereafter as the binder content was increased to 11.11%. The burning rate of briquette fuel at binder content of 3.03 - 8.57% and 11.11% are 0.75 - 0.49g/min and 0.55g/min in briquette AB, 0.69 - 0.46g/min and 0.51g/min in briquette RB and 0.66 - 0.43g/min and 0.49g/min in briquette EB. From the results, it can be affirmed that less than 1.0 g of briquettes will be consumed per minutes, which makes the briquette viable for heating purpose. However, briquette EB has the least burning rate than briquettes RB and AB.

The variation of specific fuel consumption of the briquettes as influenced by binder content was studied and the profiles shown in Figure 14. The increase in binder content from 3.03 to 8.57% decreases the specific fuel consumption. However, the specific fuel consumption increases as binder content was further increased to 11.11%. Thus, the specific fuel consumptions at binder content of 3.03 - 8.57% were 0.0172 - 0.0150 kg fuel/L water, 0.0165 - 0.0146 kg fuel/L water and 0.0163 - 0.0142 kg fuel/L water for briquettes AB, RB and EB respectively; while at binder content of 11.11%, the specific fuel consumption was 0.0164 kg fuel/L water, 0.0159 kg fuel/L water and 0.0155 kg fuel/L water for briquettes AB, RB and EB respectively. The results showed that less than 0.02 kg weight of the PKS briquettes bond with 3.03 to 11.11% cassava starch will be required to heat 1 litter of water to its boiling point. Again, in comparison, briquette EB has the least burning rate than briquettes RB and AB. These were less than 0.021 kg fuel/L water obtained for PKS briquette using 12.90% cassava flour binder (Adeniyi *et al*., 2014).

Like earlier stated, calorific value is one of the important properties of briquettes, therefore, the effect of binder content on it was studied as shown in Figure 15. Increase in binder content increases the calorific value of PKS briquettes, but later decreased as binder content was further increased. Thus, increase in binder content from 3.03 - 8.57%, resulted to increase in calorific value from 17481.09 - 20058.17 kJ/kg, 18241.94 - 20629.46 kJ/kg and 18453.49 - 21246.17 kJ/kg for briquettes AB, RB and EB respectively; while at binder content of 11.11%, the calorific value was 18373.61 kJ/kg, 18952.74 kJ/kg and 19477.73 kJ/kg for briquettes AB, RB and EB respectively.

Effect of binder content on thermal efficiency of briquettes has been studied as shown in Figure 16. Thus, as the binder content in the PKS briquettes was increased, the thermal efficiency of PKS briquettes was equally increased to an optimum point and then, decreased as the binder content was further increased. Hence, as the binder content was increased from 3.03 - 8.57%, thermal efficiency increased from 47.24 - 49.44%, 47.75 - 50.14% and 48.14 - 50.45% for briquettes AB, RB and EB respectively; but at further increase in binder content to 11.11% in the PKS briquettes, the thermal efficiency decreased to 48.15%, 48.83% and 49.22% in briquettes AB, RB and EB respectively.

CONCLUSION

Biomass in natural state is loose, which required to be compacted when prepared for briquettes. So, analysis after compression revealed that density, moisture content, ash content, volatile matters and fixed carbon of the PKS briquettes were within standards. It was also revealed that moisture content in the briquettes decreased as compression pressure, while the reverse was the case in the ash content.

The combustion analysis of the briquettes showed that ignition time, water boiling time, calorific value and thermal efficiency increased as compression pressure was increased. This was due to the limiting percolation of oxygen in the PKS briquettes while heating is in progress, which is caused by the reduction in available pore spaces in the briquettes at increased compression pressure. On the other hands, increase in compression pressure decreased the mass of briquettes consumed, burning rate of briquettes and specific fuel consumption.

These decreases showed again, that the PKS briquettes performances improved at increased compression pressures.

Binder content is another parameter that influences the performance of briquette. It does not only function as binding agent, but also improves the quality and strength of briquettes. Thus, increase in binder content in the PKS briquette increased the ignition time, water boiling time, increases the calorific value and the thermal efficiency of PKS briquettes. Although, the increase was recorded between 3.03 to 8.57% binder content, further increase in binder content up to 11.11% caused resulted to decrease in the briquettes performance. However, increase in binder content decreased the mass of briquette consumed, burning rate specific fuel consumption, which are indication of improved performance. Again, beyond 8.57% binder content, there was slight increase of the mass of briquette consumed, burning rate specific fuel consumption, which implied that the optimum cassava starch binder is 8.57%.

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