Engineering, Technology, and Sustainable Development Journal
Journal homepage: www.etsdjournal.com
Volume 1 Issue 1, 2019

Densification of *Khaya Senegalensis* Leaves for Green Coal Production

Alewo Opuada Ameh[1], Tajudeen Kolawale Bello[2], Fatima Mohammed[3] & Timothy Umma Onuh[4]
Department of Chemical Engineering, Ahmadu Bello University, Samaru-Zaria 811104, Nigeria

ARTICLEINFO

Key words:
briquettes;
densification;
energy; green coal;
Khaya senegalensis.

ABSTRACT

This study was undertaken to investigate the physical and combustion properties of briquettes produced from non-uniform particle size biomass, *Khaya senegalensis* leaves at 20%, 30%, 40%, 50% and 60% starch levels (cassava starch binder). The laboratory hydraulic press machine was employed in the briquettes production. The briquettes produced were analyzed for moisture content, ash content, burning rates, compressed density, relaxed density and calorific values which values ranged from 27- 62%, 2.35-7.2%, 1.10 - 0.5 g/min, 0.87 - 0.97 (g/cm^3), 0.367 - 0.552 (g/cm^3) and 18.0458 - 24.0223 MJ/kg, respectively. The results revealed that increase in binder concentration has a significant effect on physical and combustion properties of briquettes produced from *Khaya senegalensis* leaves. The derived briquette energy or heating values were found to be within the ranged of 18.0458 - 24.0223 MJ/kg, which is comparable to energy value to other fuel sources such as sub-bituminous coal and wood, which values are in the range of 20.000-24.730 MJ/kg, 12.23-17.00 MJ/kg respectively. Therefore, producing briquettes from leaves will be a huge opportunity in confronting both the waste problem and the domestic fuel challenge at the same time.

1.0 Introduction

The reserves of non-renewable energy sources generated by fossil fuels such as coal, crude oil and natural gas, gradually get exhausted and their price continually increase. These energy sources cause considerable increment in the emission of greenhouse gases into the atmosphere and pollution of the environment, catalyzing climate change. Due to high levels of CO_2, global warming and the rising cost of fossil fuels, the need to find clean and renewable new sources of energy has become imperative (Nunes *et al.*, 2014). As a result, international communities mandated environmental agencies to establish strict regulations and propose solutions on the reduction of the greenhouse gas emissions and pollution of the immediate environment. To this mandate, researchers have been focusing on alternative fuel resources to meet the ever-increasing energy demand and to avoid dependence on non-renewable energy sources. **Yukalang *et al.* (2018)** reported that accumulated solid waste is now the major environmental problem in

Alewo Opuada Ameh, *et al.*
Corresponding author's email: alewooameh@yahoo.com

most cities of the world and biomass constitutes a sizeable proportion of the accumulated solid waste. In the energy context, biomass is often used to mean plant-based material, but biomass can equally apply to both animal and vegetative derived material and waste (Sugathapala, 2007). Biomass comprises compounds resulting from photosynthesis processes and due to its carbon content, it may produce energy by heat or chemical processes (Nunes *et al*., 2014). Malak *et al*. (2016) reported that inherent problems with raw biomass materials compared to fossil fuel resources are low bulk density, high moisture content, hydrophilic nature, and low calorific value, which render raw biomass difficult to use on a large scale. These limitations greatly impact logistics and final energy efficiency. Coal offers a high level of fuel supply security and this can be important for commercial reasons. Low energy density of biomass compared to fossil fuels requires very high volumes of biomass (Layton, 2008), which compound problems associated with storage, transportation, and feed handling. Many researchers have attempted to convert agricultural waste as a raw material into solid biofuel briquettes/pellets using densification. Densification is the process of compaction of residues into a product of higher bulk density than the original material. This work aims at producing solid fuel by densifying leaves of *Kaya senegalensis* and characterizing the produced briquetted for fuel properties.

2.0 Materials and Methods

2.1 Materials and Equipment

Leaves sourced from Ahmadu Bello University gymnasium, Samaru-Zaria, Cassava starch, distilled water, oxygen bomb calorimeter (Parr), Gallenkamp Oven, laboratory craver hydraulic press machine, Nabertherm oven, Crucibles, aluminum pan, analytical balance (0.1mg), measuring cylinder and grinding machine.

2.2 Methodology

The methodology was categorized into five stages: sample collection, sample identification, sample pre-treatment, briquetting and characterization.

Sample collection

The biomass (leaves) was collected from dumping spot at Ahmadu Bello university gymnasium, Samaru-Zaria. and the binder (cassava starch) was purchased from Samara market, Zaria.

Sample Identification

The leaf sample together with its stem were taken to the department of Botany, Ahmadu Bello University, Samaru, Zaria for identification of which name is *Khaya senegalensis* from a family of *Maliaceae* gotten from a datum mahogany tree with a voucher number 900181.

Sample pre-treatment

The pre-treatment conducted in this study included: sorting, drying, size reduction. The feedstock was carefully sorted manually to remove impurities such as pieces of wood, bone, metal and any other unwanted materials. The sorted feedstock was then sun-dried and then subjected to size reduction process using grinding machine into a non-uniform particle size. The grounded residue was stored in a sack for the briquettes production.

Briquetting of Pre-treated Sample

According to Onuegbu *et al.* (2011), a biomass mixture was prepared for briquettes production using a constant mass of biomass (leaves) of 70g and different concentration of binder; 20 wt.%, 30 wt.%, 40wt.%, 50wt.% and 60wt.%, 145 ml of distilled water was used. For each mass of binder with constant volume of water of 145ml, three runs of briquettes were produced. Binders in form of paste were prepared using hot water of temperature 100^{o}C (20-60 wt.% binder + 145 ml of hot water H_2O).

At the start of the production of the briquettes, a hot water starch binder in the form of paste was added to biomass, stirred thoroughly for uniform mixture, the prepared mixture was charged into a laboratory hydraulic press machine. The briquettes mould consists of 12 dies arranged in three rows, each with dimension of 11cm height and 7cm diameter. The mould was covered with a top plate and compressed manually at a pressure of 5 Mpa and a dwelling time of 120 seconds was observed for the briquette formation. The briquettes formed were sun dried for 14 days before further analysis.

Characterization of Briquette

Characterization was conducted to determine the physical and chemical properties of the briquettes produced.

Compressed density

A steel cylindrical die of dimension 11 cm height and 7 cm diameter was used for this study. The die was filled freely with sample mixture and was hydraulically compressed. After the removal of **the** briquettes from the mould, the weight, length, height and volume were immediately calculated. The compressed densities (density immediately after compression) of the briquettes were determined immediately after hydraulically compressed as the ratio of measured weight to the calculated volume, equation (1). The weights of produced briquettes were determined using digital weighing balance. Pressure was applied through hydraulic at a time to the material in the hydraulic press machine and allowed for 120 secs (dwell time) before released. The pressure was monitored through dial gauge installed on the machine. A stopwatch was used for timing. Results obtained were recorded.

$$\text{Compressed density } (g/cm^3) = \frac{measured\ weight}{calculated\ volume} \quad (1)$$

Relaxed density

Relaxed density of the briquettes was determined 14 days after removal from the press in accordance with Oyedranyo (2016). The mass of the briquettes was determined using a digital weighing balance. The relaxed density (density after sun drying) were determine as the ratio of measured weight over calculated volume of the dried briquettes equation (2). Results obtained were recorded.

$$\text{Relaxed density } (g/cm^3) = \frac{\text{measured weight}}{\text{calculated volume}} \quad (2)$$

Percentage Moisture content

The moisture content was determined as follows: a known weight of the biomass sample was fetched into a known weight crucible. The crucible and its contents was measured and placed in a laboratory electrical oven and left for 3 hours at 120°C and dried. The crucible containing the dried sample was removed from the oven and the weight measured, (Onuegbu *et al.,* 2010). The moisture content was evaluated using equation (3) and results obtained were recorded.

$$\text{Percentage Moisture content } (\%) = \frac{before\ drying - oven\ dried}{oven\ dried} X\ 100\% \quad (3)$$

Calorific or heating value

The calorific values of the briquettes were determined using Oxygen Bomb Calorimeter. A known weight sample (0.3 g) of each sample was place in the support of the base of the bomb. A piece of

platinum firing wiring was stretched across the inner terminal. The other end was dipped into the center of the sample in the holder. A known weight of sample was ignited electrically and burnt in an excess of oxygen in the bomb calorimeter. The maximum rise in temperature and the corresponding calorific value for each sample were obtained from the memory of the oxygen bomb calorimeter.

Burning rate

The briquette-burning rate is the rate at which certain mass of fuel is combusted in air. Different samples of briquettes with known weight were ignited at the edge of their bases. The time taken for each briquette to burn completely to ashes was recorded. The burning rate of the briquettes samples was computed as the mass of the briquette burnt in air over the total time taken for the briquette to completely burn to ashes. The results obtained were recorded.

$$\text{Briquette burning rate} = \frac{\text{total weight of the burnt briquette}}{\text{total time taken}} \quad (4)$$

Percentage ash content

The ash content was obtained by burning a measured weight of briquette in excess oxygen. After complete combustion, the ash obtained was weighed, in essence, the ash left from the calorific value test can serve for this purpose. A known weight of briquette sample was placed in a pre-weighed crucible and transferred into a preheated muffle furnace set at a temperature of 600^{o}C for 20 minutes after which the crucible and its contents were transferred to a desiccator and allowed to cool. The crucible and its content was reweighed and the new weight noted. The percentage ash content was calculated using equation (5).

$$\%\text{ Ash Content} = \frac{W2}{W1} X\ 100\% \quad (5)$$

Where, W2 is the weight of ash after cooling, W1 is the weight of briquette sample. The result obtained were recorded.

3.0 Results and Discussion

Nature and appearance

Plate 1 Shows the cross section of the briquettes produced from *kaya Senegalensis* leaves and cassava starch binder. The briquettes have a light brown coloration. From the physical examination of the briquettes it has, a rough look due to the non-uniform particle size. It was observed that the briquettes compaction and strength increased with binder concentration. The briquettes produced from the compaction machine were strong and well formed.

Plate 1: Briquettes from *Khaya senegalensis* leaves using cassava starch as binder

Effect of Binder Concentration on Compressed Density of Briquettes

The compressed density of briquettes produced from biomass (leaves) with a non-uniform particle size and binder (cassava starch), dwelling time of 120 seconds and constant compacting pressure of 5MPa pressure is presented in Figure 1.

These densities were obtained after the removal of the briquettes from the mould. Triplicate test of briquettes mould were made per concentration of binder at constant non-uniform particle size. This was done to examine the compaction of the biomass under applied pressure.

Figure 1. shows that there is an increased in average compressed density of briquettes from 0.87 (g/cm^3) to 0.97 (g/cm^3) with increase in the concentration of binder from 20 wt.% to 60 wt.% at constant applied pressure. This result is in agreement with the findings of Elaigwu *et al*. (2010) and Imeh and Tembe (2011) which reported that there is an increase in compressive density (density immediately after compression) with increase in binder concentration. The increase observed in compressed density with increase in binder concentration at constant applied pressure could be attributed to the binder occupying pores in-between the leaves particles. The presence of cellulose, which is the main constituents of leaves, is known to contain proteinaceous materials which tend to have excellent adhesive properties High values of compressed density could be linked to moisture present in the starch, which increase the mass per unit volume of the briquettes (Elaigwu *et al*., 2010). The compressed density of briquettes is one of the indices used to assess its ability to be handled, packed and transported without breaking (Onuegbu *et al*., 2010).

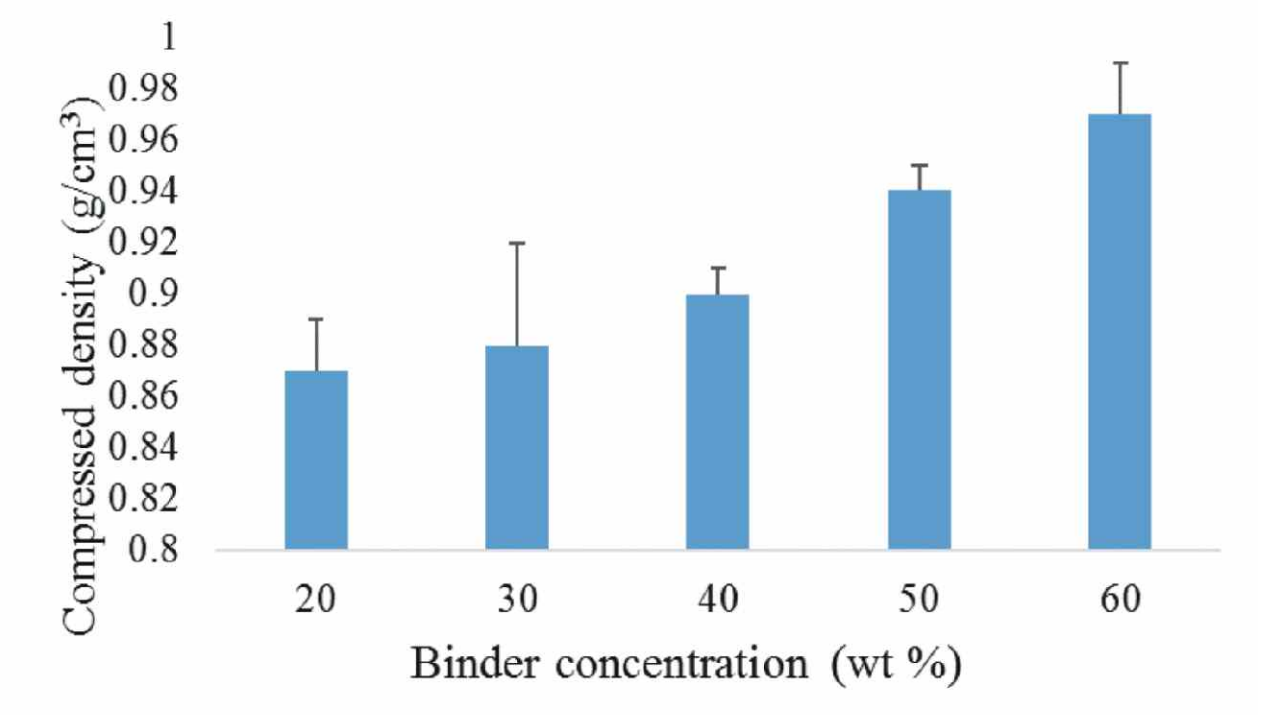

Figure 1: Effect of binder concentration on compressed density of briquettes

Effect of binder concentration on relaxed density of briquettes

The effect of binder concentration on relaxed density of briquettes produced from biomass sample with a non-uniform particle size is shown in Figure 2. The relaxed density (density after sun-drying) were determine 14 days after removal from the hydraulic press machine. Figure 2 shows there is an increase in

average relaxed density of briquette from 0.367 g/cm^3 to 0.552 g/cm^3 with increase in the concentration of binder from 20 wt.% to 60 wt.%. The relaxed density have been appreciable due to the loss of moisture content of the briquette during drying and become strong and light in weight which is desired for handling, transportation and storage of the briquettes. Briquettes relaxed densities obtained from this study were consistent with reports by Tumuluru *et al*. (2010) that briquettes made from hydraulic piston press are usually less than 1 g/cm^3 and are usually between 0.3 and 0.6 g/cm^3 in density.

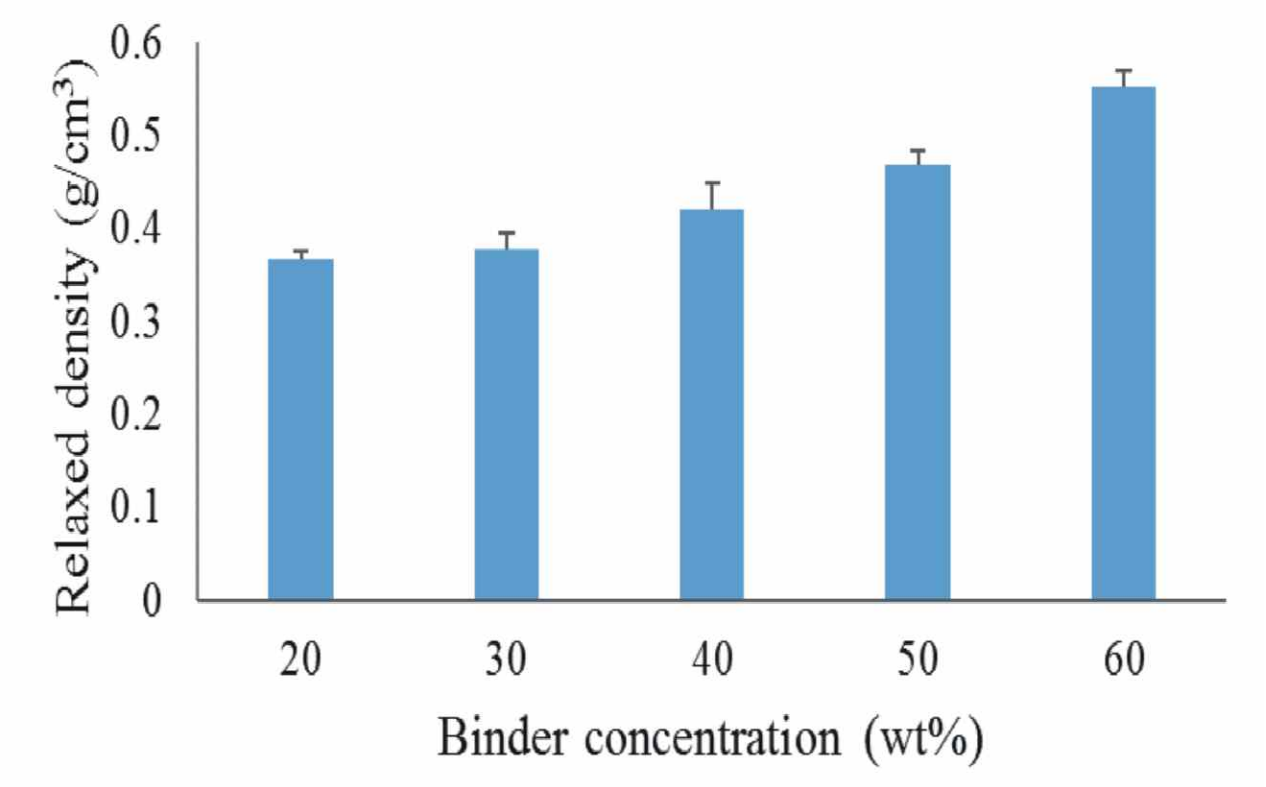

Figure 2: Effect of binder concentration on relaxed density of briquettes

The Effect of Binder Concentration on Calorific Value of Briquettes

The calorific value determines the amount of heat energy present in a material. It is a major quality index for briquette fuels. It indicates the total energy dispensed of the samples. A graph of calorific

Table 1: Combustion characteristic of *Khaya senegalensis* leaves briquettes.

	Binder concentration				
Combustion parameters	**20 (wt.%)**	**30 (wt.%)**	**40 (wt.%)**	**50 (wt.%)**	**60 (wt.%)**
% moisture content (wt. %)	27.00	40.00	47.00	50.00	62.00
% ash content (wt. %)	2.35	2.83	3.93	6.67	7.20
Calorific value (MJ/Kg)	21.70	24.02	18.05	21.25	20.91
Burning rates (g/min)	1.10	0.87	0.85	0.79	0.50

Values are mean _ SD of 3 determinants.

value (MJ/Kg) was plotted against binder concentration (wt%) as shown in Figure 3. The plot shows that binder concentration of 30wt% has high heating value of 24.0223 MJ/Kg and binder concentration of 40wt% has the lowest heating value. Binder concentration of 20 wt %, 50 wt% and 60 wt% have heating

values of 21.6971 MJ/kg, 21.2475 MJ/kg and 20.9058 MJ/kg respectively. Generally, the calorific value was observed to increase with increasing binder concentration (Chitedze *et al*., 2012). The slight difference in the heating value of this work could be associated with the non-uniform particle size use in this work and triplicate test should be done for each binder concentration due to non-uniform particle size of the biomass used to mitigate the deviation of non-uniformity. Other manufacturing conditions such as temperature and pressure also influence calorific value (Tumuluru *et al*., 2010). Calorific values obtained for corn cob, groundnut shell and spear grass (Onuegbu *et al.,* 2010; **Falemara *et al.,*** 2018) are less when compared with the results obtained in this work. All the briquettes samples produced were found to have heating values high enough to meet the heat requirement for household cooking and small-scale industrial cottage applications which is above the calorific value of fuel wood 17 MJ/kg.

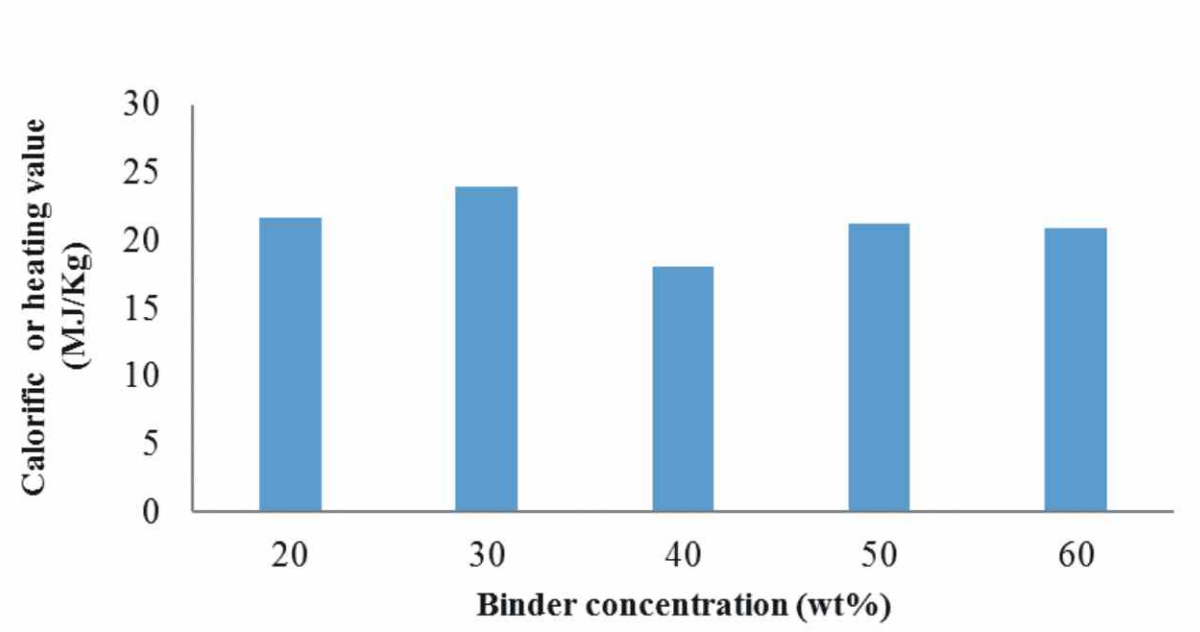

Figure 3: Effect of binder concentration on calorific or heating value

The effect of binder concentration on percentage moisture contents of briquette

The effect of binder concentration on percentage moisture content of briquettes was study and presented in Figure 2. Moisture content facilitates starch gelatinization, protein denaturation and **fiber** solubilization during briquetting (Grover and Mishra, 1996). Moisture content percentage is an important parameter in briquette production. A graph of percentage moisture content against the binder concentration is shown in Figure 4. The plot shows that there is an increase in moisture content from 27 % to 62 % with increase in binder concentration. This might be attributed to the hygroscopic nature of materials and the additional water availability from binders with increase in concentration. However, there is disagreement between the above result and the findings of Pallavi *et al*., (2013) which recommended moisture content of 5-10% for good quality briquettes and that of Chin and Siddiqui (2000) which reported that " the tolerance level of briquettes is between 8-12% depending on the nature of the feed", therefore this could be due to change in climatic condition during sun drying for 14 days, more days for sun-drying are required and also this could be due to error incurred during oven drying due to electrical power failure.

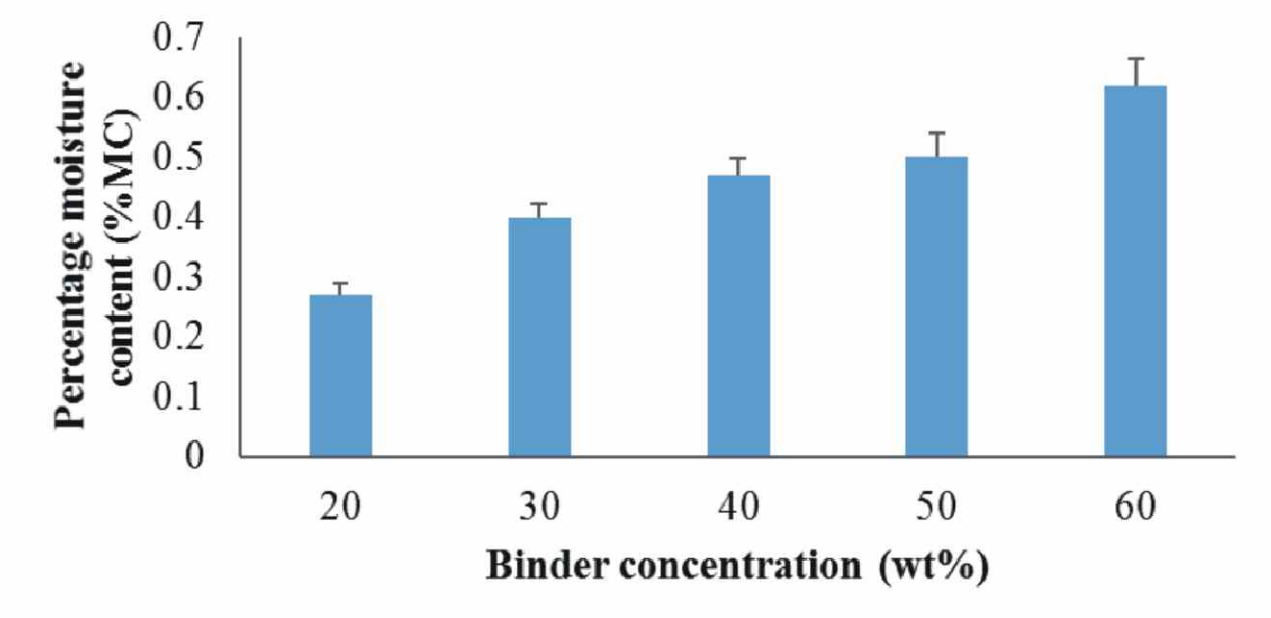

Figure 4: Effect of binder concentration on Percentage moisture content

Effect of Binder Concentration on Burning Rates of Briquettes

The effect of binder on the burning rate of briquettes was studied with a non-uniform-particle size as presented in Table 2. The briquettes burning rate was determine in a controlled chamber. A plot of average burning rate against the binder concentration (wt%) is shown in Figure 5. The plot shows that there is a decreased in burning rates from 1.10 g/min to 0.5 g/min with increase in concentration of binder from 20 wt% to 60 wt%. Briquettes with high burning rates are more desirable in combustion as they burn off readily. The result is in agreement with the findings of Ajayi and Lawal (1997) which studied the effect of binder on the burning rate of the sawdust briquettes with palm oil sludge as binder. The study discovered that the binding of the sawdust by the sludge prevented the fast burning of the briquettes hence experienced reduction in the weight loss as the sludge content increases. Therefore, as observed from Figure 5, briquettes without binder or with little amount of binder burn off faster than those with binder.

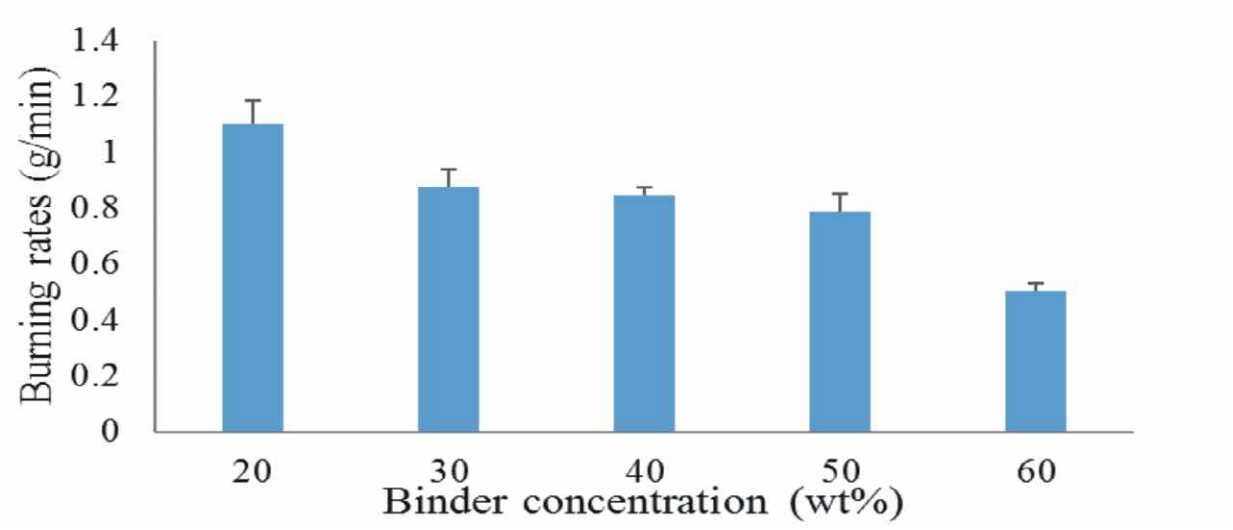

Figure 5: Effect of binder concentration on burning rates of briquettes

Effect of Binder Concentration on Percentage Ash Content (% Ash) of Briquettes

The effect of binder concentration on percentage ash content of briquettes was study and presented in Table 2. The ash content of the briquette is the amount of ash that remains after the briquettes is burned or incinerated. Knowledge of the ash content tells the extent of clogging up of the burning medium. High ash content decreases the burning rate and reduces the heating value of fuel. A graph of percentage ash content was plotted against binder concentration shown in Figure 6. The plot shows that there is increase in percentage ash content from 2.35 to 7.2 with increase in binder concentration from 20 wt% to 60 wt%. Ash content percentage is expected to be between 5 and 15 % as their excess is detrimental for proper combustion of solid fuels (Shaha, 1974). The ash content percentages recorded for this work shows that they are even better than coal samples as reported by Onuegbu *et al. (*2010). Low ash content offers higher heating value for briquettes but high ash content results into dust emissions which lead to air pollution and affects the combustion volume and efficiency (Obi *et al*., 2013).

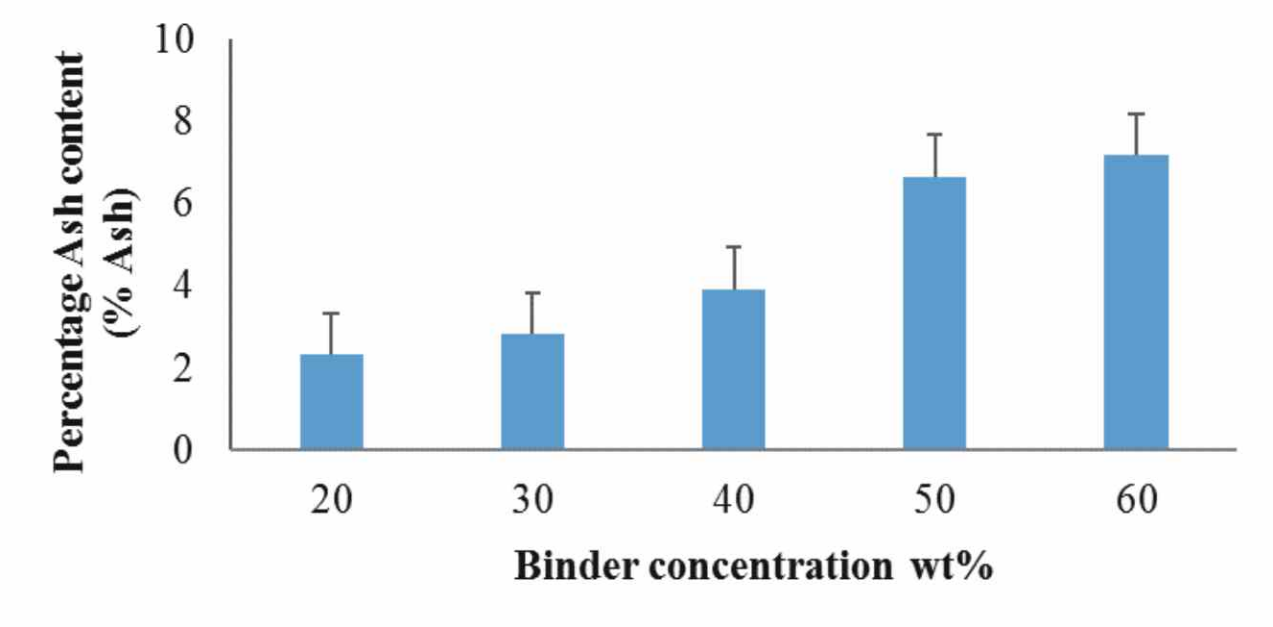

Figure 6: Effect of binder concentration on percentage ash content of briquettes

4.0 Conclusion

This study investigated the potentials of using biomass (*Khaya Senegalensis* leaves) to produced briquettes as an alternative energy source using cassava starch as a binder at constant non-particle size. Factors investigated to affect the quality of the briquette include; binder concentration, moisture content, percentage ash content, burning rate, calorific value, compressed and relaxed density (density after sun-drying). The percentage moisture content, percentage ash content, burning rates, compressed density, relaxed density and calorific values ranged from 27 - 62 %, 2.35-7.2, from 1.10 - 0.5 g/min, 0.87 - 0.97 (g/cm^3), 0.367 - 0.552 (g/cm^3) and 18.0458 - 24.0223 MJ/kg, respectively. It was observed that increase in binder (cassava starch) concentration has a significant effect on moisture content, percentage ash content, burning rate, calorific value, compressed and relaxed density of briquettes produced from *Khaya Senegalensis* leaves. Calorific value is a major quality index for briquette fuels. The derived briquette energy or heating values were found to be within the range of 18.0458 - 24.0223 MJ/kg, which is comparable to energy value to other fuel sources such as sub-bituminous coal and wood which values are in the range of 20.000-24.730 MJ/kg, 12.23-17MJ/kg respectively. Therefore, producing briquettes

from leaves will help to increase the sources of energy for domestic and industrial use in developing economy, also it will be a huge opportunity in confronting both the waste problem and the domestic fuel challenge at the same time. Fuel briquettes, which can be made from different types of waste material, offer a low-cost alternative domestic fuel to low-income families for their daily meals.

References

Ajayi O.A., and Lawal, C.T., (1997), Hygroscopic and combustion characteristics of sawdust briquettes with palm oil sludge as binder, *Journal of Agricultural Engineering and Technology*, 5: 29–36.

Chin, O. C and Siddique, K.M., (2000), Characteristics of some Biomass Briquettes Prepared Under Modest Die Pressure", *Biomass and bioenergy*, 18:223-228

Chitedze, J., Monzerezi, M., Kalenga-Saka, J.D. and Steenkamp, J. (2012), Binding Effect of Cassava Starch on the Compression and mechanical Properties of Ibuprofen Tablets, *Journal of Applied Pharmaceutical Sciences*, 2(4): 31-37.

Elaigwu, V., Adetogun. A.C and Tembe, E.T., (2010), "Combustion properties of briquettes produced from Groundnut shell and rice husk", 4 - 20.

Falemara B.C., Joshua V.I., Aina O.O. and Nuhu R.D. (2018), Performance evaluation of the physical and combustion properties of briquettes produced from Agro-wastes and wood residues, *Recycling*, *3*, 37; doi:10.3390/recycling3030037.

Grover, P.D. and Mishra, S.K., (1996), Biomass briquetting: Technology and practices, Food and Agriculture Organization (FAO) of the United Nations. Regional Wood and Energy Development Programme in Asia, Bangkok, Thailand.

Imeh, S. T. and Tembe, E.T. (2011): Combustion properties of Briquettes produced from sawdust of *khaya senegalensis* and *Gmelina arborea*, 14-18.

Layton B. (2008), A Comparison of Energy Densities of Prevalent Energy Sources in Units of Joules Per Cubic Meter, *International Journal of Green Energy*, 5: 438 – 455.

Malak. K. C., Fernández C., Swaminathan M., Sebastiá A. and Arora D., (2016), Green Coal: a New Energy Source from Leaves 3rd International Conference on Power and Energy Systems Engineering, CPESE, pp 8-12 Kitakyushu, Japan.

Nunes, L., J., Matias R.O and Catalaõ, J.P, (2014), *Mixed biomass pellets for thermal energy production: A review of combustion models*, Elsevier, *Applied Energy*, 127: 135–140.

Obi O. F., Akubuo, C. O., Okonkwo, W. I, (2013) "Development of an Appropriate Briquetting Machine for Use in Rural Communities", *International Journal of Engineering and Advanced Technology (IJEAT)*, volume 2, issue 4.

Onuegbu, T., Ogbu, I., IIochi,N., Ekpunobi,E.,Ogbuagu,A. (2010), Enhancing the properties of Coal Briquette Using Spear Grass (Imperata Cylindrica), Leonardo Journal of Sciences, 17: 47-58.

Onuegbu, T.U., Ekpunobi, U. E., Ogbu, I.M., Ekeoma, M.O., Obumselu, F.O., (2011), Comparative studies of Ignition Time and Water Boiling Test of Coal and Biomass Briquettes Blend, International Journal of Research and Reviews in Applied Sciences (IJRRAS), 7 (2): 153 – 159.

Pallavi, H.V, Srikantaswamy. S., Kiran, B.M., Vyshnavi, D.R., and Ashwin, C.A. (2013), Briquetting Agricultural Waste as an Energy Source, *Journal of Environmental Science, Computer Science and Engineering & Technology*, 2(1): 160-172.

Shaha, AK (1974), Combustion; engineering and fuel technology. Oxford & IBH Publishing Company. (Accessed July 24, 2018).

Sugathapala A.G.T. (2007), Biomass Gasification in Sri Lanka*, Asia Pacific Tech Monitor, Biomass Energy Technologies*, 24(4): 42-50.

Tumuluru, J. S., Sokhansanj, S., Lim, C.J., Bi,T., Lau,A., Melin, S., Sowlati,T., Oveisi, E. (2010), Quality of wood pellet produced in British Columbia for Export. *Applied Engineering in Agriculture* 26(6):1013-1020

Yukalang N., Clarke B. and Ross K. (2018), Solid Waste Management Solutions for a Rapidly Urbanizing Area in Thailand: Recommendations Based on Stakeholder Input, International Journal of *Environmental Research and Public Health*, 15, 1302.