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Optimum proportion of starch binder and palm kernel shell hybrid additive in the formation of sawdust based composite briquette.

Seun Oyelami[1], Wasiu Oyediran Adedeji[1], Franscis Olukunle Ademokoya[1], Abideen Temitayo Oyewo[1*], Kehinde Adenike Oyewole[2], Babajide Joshua Ojerinde[1], Olakunle Olukayode[1]

[1] Mechanical Engineering Department, Osun State University, Osun State, NIGERIA.
[2] Chemical Engineering Department, Osun State University, Osun State, NIGERIA.
* Correspondence email: Abideen Temitayo OYEWO (abideen.oyewo@uniosun.edu.ng)

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ABSTRACT

Briquette making involves collection of combustible materials not useable because of their low density and compressing them into solid fuel of convenient shape. Briquette has lower ash content, high heat and calorific value than most fuels. Thus, this study investigated 200g of pure sawdust and five other briquettes of percentage by mass ratios of sawdust to palm kernel shell of 90:10, 80:20, 70:30, 60:40, and 50:50, were made dry and without binder. The briquettes were tested for crushing strength and calorific value. The best of the briquettes which is 70:30 percentages was picked and its composition was used to make another set of five briquettes but with starch of masses 10g, 20g, 30g, 40g and 50g respectively. The briquettes with starch content were tested for calorific value only. Consequently, the data obtained from the results showed that addition of palm kernel shell increases the calorific value from 15,668KJ/kg when there was no palm kernel shell addition to 18,397kJ/kg at palm kernel shell addition up to 30% beyond which the calorific value decreases. However, addition of starch binder to the briquette raised the calorific value to 20,377kJ/kg when the starch addition was up to 4.8% beyond which the calorific value decreases. Result shows that 4.8% of starch addition was insufficient for the composite briquette. However, 13% of starch binder briquette a calorific value of 20,005kJ/kg is considered the best. 13% of starch binder briquette could be developed for usage in boiler, heating purpose and gasification plants to replace conventional fuel sources.

1 Introduction

The world energy consumption is seriously increasing at a phenomenal rate when compared to the world population. It is known that about 80% of the world's energy demand is met by fossil fuels which are mainly coal, petroleum oil and natural gas [1]. These fuels, on which we have depended, are non - renewable and it is obvious that their supply is not keeping up with world's demand for energy. The world production of fossil fuels will start to depreciate in twenty to thirty years' time and this has been the major concern of the entire world [2-4]. Nigeria has been facing energy crisis over the past ten to fifteen years despite the fact that it is an oil producing and exporting nation. This has led to acute shortage of petroleum and allied products thus affecting the nation's economy and the standard of living of its citizens [5-8].

In order to alleviate this problem, a lot of attention has to be given to the search for alternative energy sources that will be renewable i.e., they can be replenished more rapidly [7-9]. This renewable energy includes solar energy in its direct form, wind, geothermal, water and biomass [9, 10]. Out of all these types of renewable energy, Biomass which is the generic name given to all dry plant materials and organic waste has found more recognition. This is because its development always results in a cleaner environment and at the same time can provide the means to recycle waste thus turning what is called rubbish to something valuable [9].

*Corresponding author: abideen.oyewo@uniosun.edu.ng

Examples of biomass input materials include sawdust, rice husk, palm kernel shell, paper, animal dung, etc. Plant biomass in the form of wood was the first and for a long time, universal and only fuel providing external energy for cooking, warmth, and later, manufacturing and until recently it was generally abundant [11, 12]. Since 1973, when oil price began to rise, considerable interest has been shown in the possibility of using various present day biomass sources especially those from wood or wood wastes otherwise known as sawdust to produce fuel substitutes and chemical feedstock. Sawdust which is commonly found at sawmills in the southern part of Nigeria is always burnt off as a waste and this would have been a better means of converting what could be termed as rubbish to something valuable which can be used as an alternative fuel for cooking.

Literature has reported that the addition of palm kernel shell in appropriate proportion would increase the calorific value of briquette [13] because a good quality briquette should be strong enough to withstand damage during transportation, storage and stoking [14, 15]. While there is abundant literature on solid briquette, there is paucity of studies on efforts to determine the best optimum proportion of biodegradable starch and palm kernel shell hybrid in a sawdust composite briquette. This work therefore aims to evaluate the optimum proportion of starch binder and palm kernel shell required to produce briquettes of high quality in a quest to investigate their crushing strength, calorific value, moisture content and boiling test.

2 Materials And Methods

Sawdust of soft wood and charred palm kernel shell were collected and screened of impurities separately. The sawdust was dried in the oven at 150^{o}C for 30 minutes, allowed to cool for 10 minutes and then sieved to 20-mesh particles. After sieving, the sawdust was dried again in the oven for another 30 minutes and then allowed to cool for some minutes. The palm kernel shell was crushed after which it was ground. It was also sieved to 20-mesh particles and then dried in the oven at 150^{o}C for 45 minutes after which it was allowed to cool for about 30 minutes.

The sieved sawdust and the palm kernel shell were mixed together in the following percentage by mass ratios of sawdust to palm kernel shell: 90:10, 80:20, 70:30, 60:40 and 50:50, making five different samples of feedstock (see Table 2. 1). Each of these samples were kept in a labeled bag for identification purposes. 200g of each sample was drawn from each bag and briquetted dry and without binder using the fabricated briquette molding machine. A control of 100% pure sawdust dry and without binder was also set.

The briquettes produced were dried in the electric oven for 15 minutes at temperature of 150^{o}C. The five composite briquettes and the one with 100% pure sawdust were tested for crushing strength, specific fuel consumption, percentage heat utilization and calorific value. The crushing strength test was carried out using crushing machine, the specific fuel consumption and percentage heat utilization were determined by using the briquettes to boil 1kg of water.

The briquette with percentage by mass ratio of sawdust to palm kernel of 70:30 was found to have reasonable crushing strength of 12.15N/mm^2, specific fuel consumption of 0.49kg/kwh, and percentage heat utilization of 3.8 and the highest calorific value of 18,397kJ/kg. This briquette was picked and its percentage composition was used to produce another set of five briquettes using the same mass of mixture of sawdust and palm kernel shell but with varying proportions of starch gel ranging from 50g to 250g as binder at some temperature between 80^{o}C and 100^{o}C for good biding. The five briquettes containing starch produced were weighed completely wet using scale balance. The values obtained during the completely wet weighing were presented in Table 2. 2.

Table 2. 1: Mass of sawdust and palm kernel shell in briquette sample

Feedstock sample	Mass of sawdust (g)	Mass of palm kernel shell (g)	% by mass ratio of sawdust to palm kernel shell
Control sample	200	0	100:0
1	180	20	90:10
2	160	40	80:20
3	140	60	70:30
4	120	80	60:40
5	100	100	50:50

Table 2. 2: Varying proportion of starch-gel in the briquette samples

Briquette sample	Mass of starch in each briquette sample (g)	Mass of briquette before drying (g)
1	50	230
2	100	280
3	150	330
4	200	380
5	250	430

2.1 Heat Gained by the Feedstock during Mixing with Hot Starch – Gel

During mixing of starch - gel to a mixture of sawdust and palm kernel shell, the heat transferred Q from the starch - gel to the mixture of sawdust and palm kernel shell is given in Equation #2.1. similarly, the heat gained by the feedstock for each of the five samples of briquette was calculated using the Equation 2.1 [16].

$$Q = MC\Delta t \qquad (2.1)$$

Where:
m = mass of starch - gel (kg)
C = Specific heat capacity of water, 4.2kJ / kgK
Δt = Temperature rise of the feedstock.

2.2 Drying of Briquettes

The five samples of briquette containing starch were weighed wet, recorded and dried in the electric oven at a temperature set of 150^{o}C for 30 minutes and then cooled in ambient air for 10 minutes and then reweighed. The drying, cooling and weighing of the briquettes were performed for twelves (12) times until the briquette's masses were constant. The average was calculated by means of standard deviation.

2.3 Moisture Content Estimation

The mass and the percentage mass of moisture content lost from each of the briquettes during drying were estimated using the Equations 2.2 (a) and (b). The results obtained with each briquette are presented on Table 2.5

$$M_{ml} = M_{wb} - M_{db} \qquad 2.2\ (a)$$

$$\%\ M_{ml} = (M_{wb} - M_{db}) / M_{wb} \qquad 2.2\ (b)$$

Where:
M_{ml} = Mass of moisture content lost from the briquette during drying
M_{wb} = Mass of wet briquette before the 1st drying
M_{db} = Mass of briquette after final drying.

2.4 Estimation of Briquette Cross-sectional area, Volume and Density

The cross-sectional area, volume and density of each of the five briquette samples were also calculated using Equation 2.3 (a), 2.4 (b) and 2 (c) respectively [17]. Consequently, the varying size of the briquette is presented in Figure 2.1.

$$A = \frac{\pi d^2}{4} \qquad 2.3\ (a)$$

$$V = Ah \qquad 2.3\ (b)$$

$$Q = \frac{m}{V} \qquad 2.3\ (c)$$

Where M is the mass (g), h is height (cm), A is the cross-sectional area (cm^2), V is the volume (cm^3), d is the density of briquette (g/cm^3).

2.5 Estimation of Percentage Starch in the Briquette Samples

The starch content in each of the briquette samples was estimated and stated on Table 2.7 using the mathematical expression using Equations 2.4 and 2.5, respectively [18].

$$M_{ds} = \frac{(M_{sgu}\ x\ M_{tds})}{m_{tsg}} \qquad 2.4$$

$$\%M_{ds} = \frac{M_{ds}}{M_s + M_{pks} + M_{ds}}\ x\ 100 \qquad 2.5$$

Where:
M_{ds} is mass of dry starch in the briquette sample
M_s is mass of sawdust
M_{pks} is mass of palm kernel shell
M_{sgu} is mass of starch-gel in the briquette sample
M_{tsg} is the total mass of starch-gel prepared for all the briquette samples and
M_{tds} is the total mass of dry starch prepared to starch-gel.

2.6 Crushing Strength Test

The first two categories of briquette samples were tested for crushing strength using 50-C41/C 2000KN capacity compression machine. To carry out the test, the sample was placed on the machine press and compressed with increasing load when the machine was switched on. Immediately the sample began to deform, the load was noted and recorded. This process was repeated for the remaining samples one after another and the crushing strength was determined in each case using Equation 2.6 [19].

$$\text{Crushing Strength} = \text{Crushing Load (N)} / \text{Cross-sectional area (mm}^2\text{)} \quad 2.6$$

2.7 Calorific Value Test of Briquettes

2.7.1 Briquettes without starch binders

The briquette with 100% pure sawdust and without starch binder was first tested for calorific value followed by the five briquettes with varying proportions of sawdust and palm kernel shell. To carry out the test, the equipment was switched on and the computer was set to kJ unit of heat. Then 0.5g of briquette sample was weighed into a bomb dish and the value was imputed to the computer. The firing cotton was tightened to the firing wire and the sample was ignited via the bomb lid to the bomb. The bomb was filled with oxygen gas at 3kPa and inserted into the calorimeter (Model XRY – 1A). After three minutes the reading was taken and the bomb was brought out and degassed. This process was repeated for all the samples until all of them were tested.

2.7.2 Briquettes with starch binders

The five briquettes with starch binder were tested for calorific value following the same procedural steps taken during the test for calorific value of the initial six briquettes without starch binder. The calorimeter bomb oxygen filling station, calorimeter being ready to receive the bomb and the calorimeter reading the calorific value of briquette sample.

2.8 Water Boiling Test of Briquette

The Water Boiling Test (WBT) was used to evaluate the Percentage Heat Utilization (PHU) and the Specific Fuel Consumption (SFC) of the five briquettes without starch. 0.8kg of briquette was burnt in a solid fuel stove to boil 1Kg of water. The briquette burned with negligible and odourless smoke. The briquette burning effectiveness was increased by its percentage heat utilized and its specific fuel consumption. The PHU of the briquette is the percentage of heat released by burning the briquette [9, 20]. The SFC is the total quantity of briquette used for the simulated cooking process divided by the amount of water boiled. The PHU and SFC for each briquette were determined using the Equation 2.7 and 2.8 which are Baldwin Equations [21].

$$SFC = \frac{M_f}{M_{wf}} \quad 2.7$$

Where:
M_f *is the mass of fuel consumed (kg) and*
M_{wf} *is the mass of water at the end of the phase (kg)*

$$PHU = \frac{4.2m_{wi}\ (T_f - T_f) + 2260\ (m_{wi} - m_{wf})}{m_f\ CV}\ x\ 100 \quad 2.8$$

Where:
M_{wi} *is the mass of water at the beginning of phase,*
T_i *is the initial temperature of water (K),*
T_f *is the final temperature of water (K),*
CV is the calorific value of fuel in kJ/kg,
4.2 is the value of specific heat of water in kJ/kgK and
2260 is the value of latent heat of vaporization of steam in kJ/kg.

The numerator and the denominator of Equation 2.7 are the quantity of heat required to boil 1 kg of water and the quantity of heat supplied by the fuel to boil the water respectively.

3 Results and Discussion

3.1 Heat Gained by the Feedstock during Mixing with Hot Starch – Gel

From the Table 3.1, it was observed that the heat transferred from the hot starch - gel to the mixture of sawdust and palm kernel shell increases with the mass of hot starch - gel added up to 200g of starch after which the heat transfer begins to decrease. Beyond 200 g, the heat gained by the feedstock declined, showing that increase in temperature had no effect. Heat gained by the feedstock during mixing with hot starch – gel is presented in Table 3.1.

Table 3. 1: Heat gained by the feedstock during mixing with hot starch - gel.

Feedstock sample	Mass of starch-gel added to feedstock sample (g)	Initial Temperature of T_1 (ºC)	Final Temperature T_2 (ºC)	Heat gained by feedstock Q (kJ)
1	50	88	55	6.93
2	100	85	60	10.50
3	150	83	64	11.97
4	200	82	67	12.60
5	250	80	70	10.50

3.2 Drying of Briquettes

The variation of the masses of the briquette as recorded during drying is presented in Table 3. 2. there was loss of masses due to evaporation of water during the drying. It was noted that there was about 20g of moisture content was lost from each briquette during each 30 minutes drying until the mass became constant and the drying stopped.

Table 3. 2: Variation of briquette mass during drying

Briquette Sample	Initial mass (g)	Mass After 12^{th} Drying (g)
1	230	210 ± 10.1
2	280	220 ± 9.2
3	330	230 ± 11.5
4	380	240 ± 6.0
5	430	250 ± 10.7

3.3 Moisture Content Estimation

From the

Table 3. 3, it was observed that the percentage by mass of moisture content lost during drying increases with mass of briquettes. This is due to the different varying mass proportion of starch binder in the briquette sample.

Table 3. 3: Moisture content lost from the briquette

Briquette sample	Mass of briquette before first drying (g)	Mass after final Drying (g)	Mass of moisture content lost (g)	% by mass of moisture content lost
1	230	210	20	8.69
2	280	220	60	21.43
3	330	230	100	30.30
4	380	240	140	36.84
5	430	250	180	41.86

3.4 Estimation of Briquette Cross-sectional area, Volume and Density

Considering the cylindrical configuration of the briquettes with a diameter of 96 mm, the cross-sectional area was calculated as 72.38cm^2, but with variable height. Figure 3. 1 presents the samples of briquette produced for characterizations.

Table 3. 4: Volumes and Densities of briquettes with starch content

Briquette sample	height of briquette (cm)	Final mass of briquette (g)	Volume of briquette (cm^3)	Density of briquette (g/cm^3)
1	5.0	210	361.9	0.580
2	5.1	220	369.1	0.596
3	5.2	230	376.4	0.611
4	5.3	240	383.6	0.626
5	5.4	250	390.9	0.640

Figure 3. 1: Volumes and Densities of briquettes with starch content

3.5 Estimation of Percentage Starch in the Briquette Samples

Table 3. 5: Starch content in briquette sample

Briquette sample	Mass of sawdust (g)	Mass of palm kernel shell (g)	Mass of starch-gel (g)	Mass of dry starch (g)	% by mass of dry starch
1	140	60	50	10	4.8
2	140	60	100	20	9.1
3	140	60	150	30	13.0
4	140	60	200	40	16.7
5	140	60	250	50	20.0

3.6 Crushing Strength Test

The crushing loads and strengths of 100% pure sawdust briquette and briquettes of sawdust with palm kernel shell without starch binder are given on Table 3. 6.

Table 3. 6: Crushing strength of briquette without starch binder

The Briquette Sample	% by mass of sawdust	% by mass of palm kernel shell	Crushing load (N)	Crushing strength (N/mm^2)
Control sample	100	0	140,000	19.34
1	90	10	128,000	17.68
2	80	20	104,000	14.37
3	70	30	88,000	12.15
4	60	40	52,000	7.18
5	50	50	36,000	4.97

Table 3. 6 above shows that the crushing strength of briquettes decreases with increase in mass of palm kernel shell. This is due to the fact that the cohesive force (the intermolecular force) between the molecules of sawdust and palm kernel shell is

weak. This could probably be firstly because the mixture of sawdust and palm kernel shell is not homogenous, and secondly the high momentum is created by the molecule of palm kernel shell on the molecule of sawdust due to external force on it. Therefore, the more the palm kernel shell additive the less the crushing strength of briquette.

Figure 3. 2: Effect of varying palm kernel shell on Crushing Strength of Briquette

3.7 Calorific Value Test Result

3.7.1 Briquettes without starch binders

The calorific value of briquette with 100% pure sawdust and those of the various compositions of sawdust and palm kernel shell without starch binder are given on Table 3. 7. Similarly, Figure 3. 3 shows that addition of palm kernel shell increases the calorific value of briquette until the percentage of palm kernel shell is 30%. At this point the calorific value is 18, 397kJ/kg. Further addition of palm kernel shell beyond 30% decreases the calorific value of the sawdust based composite briquette. This result was a confirmation of Kuti's research work that the briquette with 70:30 percentage ratio of sawdust to palm kernel shell gave the highest calorific value after testing briquettes from various ratios of percentage by mass of sawdust to palm kernel shell [22-24].

Table 3. 7: Calorific values of briquettes without starch binder

Briquette sample	% by mass of sawdust	% by mass of palm kernel shell	Calorific value (kJ/kg)
Control sample	100	0	15,668
1	90	10	15,790
2	80	20	17,910
3	70	30	18,397
4	60	40	18,033
5	50	50	17,118

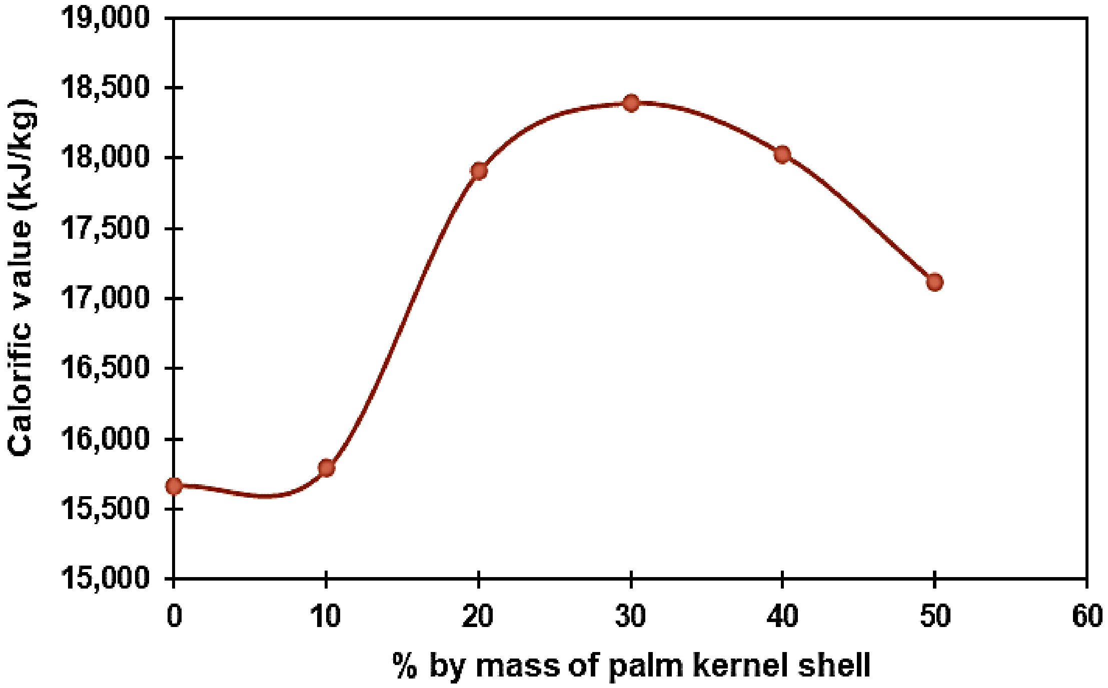

Figure 3. 3: Effect of Varying Palm Kernel Shell on Calorific Value of Briquette

3.7.2 Briquettes with starch binder

Calorific values of briquettes with starch binder are presented in Table 3. 8 while the effect of starch concentration on calorific value of briquettes is presented in Figure 3. 4. Also, Table 3. 8 shows that the calorific value increases from 18,397kJ/kg at 0% starch binder to a value of 20, 377kJ/kg at 4.8 % starch binder. This could probably be due to formation of ethanol during fermentation of starch in the briquette because the briquette drying took several days. However further increase in percentage of starch addition reduces the calorific value until the value decreases to 18,947kJ/kg at 20% starch binder. This could be due to the fact that the calorific value of pure starch is 17,478kJ/kg [16]. This value is less than the initial calorific value which was 20,377kJ/kg, though there would be more ethanol due to increase in starch addition. Since different volumes of the same fuel have equal calorific value, increase in ethanol addition would not have any effect on the briquette calorific value but the lower calorific value of starch would probably lower the briquette calorific value.

Table 3. 8: Calorific Values of briquette with starch binder

Briquette sample	% by mass of starch in Briquette sample	Calorific Value (kJ/kg)
Sample without Starch	0	18,397 ± 109
1	4.8	20,377 ± 111
2	9.1	20,158± 113
3	13.0	20,005± 125
4	16.7	19,196± 103
5	20.0	18,947± 112

From Figure 3.4, there was appreciable increase in caloric value from 0 – 13.0 % starch quantity. It could be observed that raising the percentage concentration of starch in the briquette beyond 10 % led to a decline in caloric values of the briquettes. Raising the binder level leads to a decline in the gross calorific value, as expected due to the reduction in the char fraction, which significantly influences the overall calorific value of the briquettes [7, 8].

Figure 3. 4: Effect of Starch Concentration on Calorific Value of Briquette

3.8 Water Boiling Test Result

The specific fuel consumption and the percentage heat utilization of each briquette sample without starch binder were shown on Table 3. 9 and Table 3. 10, respectively.

Table 3. 9: Specific fuel consumption of briquette sample

Briquette sample	% by mass of sawdust	% by mass of palm kernel shell	Mass of fuel consumed (g)	Specific Fuel Consumption
1	90	10	0.64	0.65
2	80	20	0.55	0.56
3	70	30	0.48	0.49
4	60	40	0.45	0.46
5	50	50	0.43	0.44

Table 3. 10: The percentage heat utilization of briquette sample

% by mass of palm kernel shell	Calorific value (kJ/kg)	Initial Temperature of water (^{O}C)	Final Temperature of water (^{O}C)	Percentage Heat Utilization
10	15,790	31	100	3.3
20	17,910	31	100	3.4
30	18,397	31	100	3.8
40	18,033	31	100	4.1
50	17,118	31	100	4.6

Figure 3. 5 shows that the specific fuel consumption decreases with increasing mass of palm kernel shell additive. This could be because the particle of palm kernel shell has higher density than that of sawdust particle, and the higher the density of fuel the lower the mass consumption of the fuel during combustion.

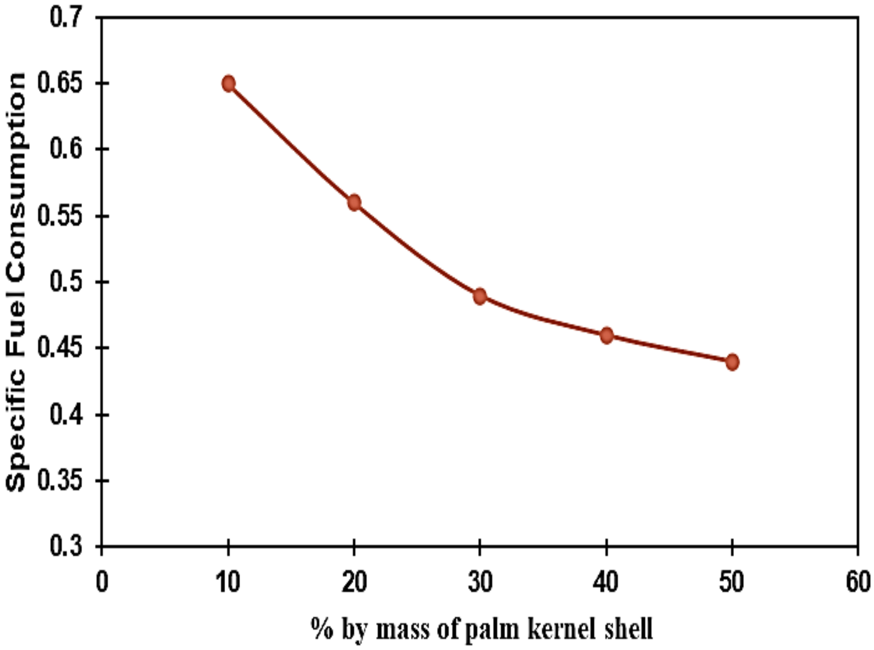

Figure 3. 5: Specific fuel consumption of briquettes with varying % by mass of palm kernel shell

From Figure 3. 6, it was observed that the percentage heat utilization increases with increase in percentage by mass of palm kernel shell. This could probably be because palm kernel shell has higher calorific value than sawdust. Therefore, the more the palm kernel shell additive the higher the percentage of heat given out by the fuel during combustion.

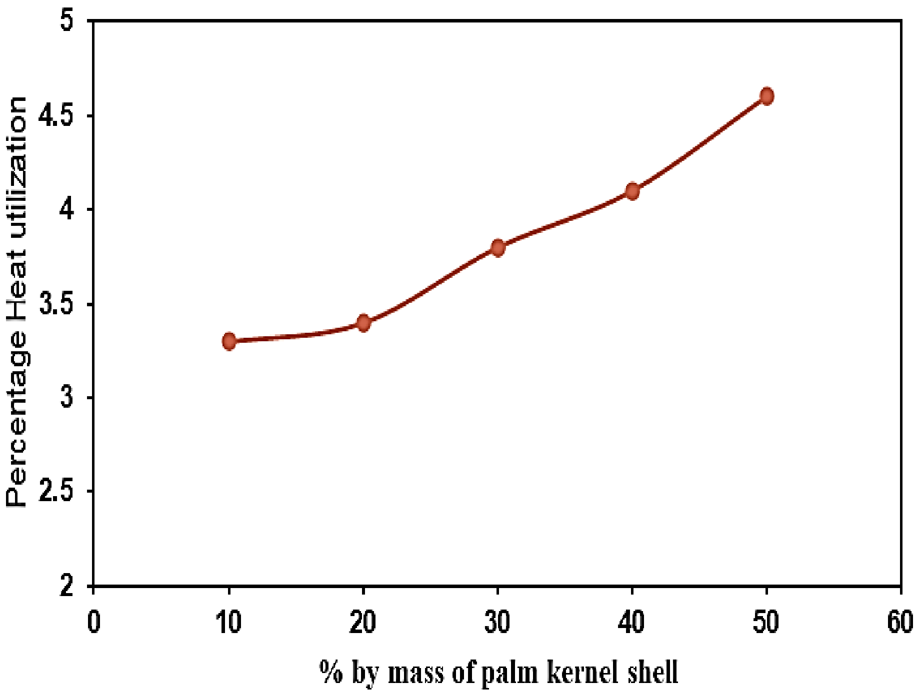

Figure 3. 6: Effect of palm kernel shell on percentage heat utilization of briquette

4 Conclusion

Manually operated briquette making machine was designed and constructed. This machine was used to make three set of briquettes, namely 100% pure sawdust, varied proportion of sawdust and palm kernel shell, and sawdust and palm kernel shell with varied proportion of starch binder. Briquettes without starch binder were tested for crushing strength and calorific value. The results show that the crushing strength decreases with palm kernel shell addition, while the calorific value increases with increasing palm kernel shell until the percentage concentration of palm kernel shell is 30%, beyond which the calorific value decreases. Beyond 30 % palm kernel shell reinforcement, the reinforcement becomes excessive with insufficient binder, leading to poor compaction and calorific values The calorific value at this concentration is 18,397kJ/kg. The 70:30 percentage by mass of sawdust to palm kernel shell produced with varied starch content having being tested for calorific value reveals that calorific value decreases appreciably from 20,377kJ/kg to 18,397kJ/kg but further increase in starch addition decreases the calorific value. Though the briquette with 4.8% of starch has the highest calorific value the quantity of starch in it is not enough for good binding but the one with 13% of starch with calorific value of 20,005 kJ/kg is therefore recommended. 13 % starch content is considered the best because of it has highest char fraction and little caloric value. Thus, it has a greater potential as a replacement for conventional heating sources.

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