

PAPER 107 – ENERGY ANALYSES OF BRIQUETTES PRODUCED FROM TORREFIED LOCALLY SOURCED GROUNDNUT SHELL

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ABSTRACT

In this work, the energy analyses of Briquettes produced from locally sourced Groundnut Shell was determined and the proximate and ultimate analysis of the torrefied Groundnut Shell was carried out. In the preparation of the Briquettes (Groundnut Shell Briquette), cassava starch was used as a binder. The concentration of the binder was varied between 20 – 60 wt% while 70g of the sample was used throughout the experiment. The Calorific Values of the produced Briquettes were done using the Oxygen Bomb Calorimeter. Design Expert Central Composite design tool was used in the Design and Response Surface Methodology was used to optimize the Calorific Values of Groundnut Shell Briquettes. The Groundnut Shell Briquettes with optimized conditions were produced using 39.525 wt% binder concentrations, 57.512 seconds dwelling time and 4.316 MPa compaction pressure. The result showed that the Groundnut Shell Briquette gave 17.869 MJ/Kg Calorific Value. The Groundnut Shell Briquette gave the water boiling test and burning rate of 15.82 min and 0.22 g/min respectively. Therefore, Groundnut Shell briquette will be a good source of alternative energy since it is within the range of 17.00 MJ/kg – 24.00 MJ/kg.

KEYWORDS: Briquettes, Calorific Value, Water Boiling Test, Burning Rate, Dwelling Time.

1. INTRODUCTION

The decrease in the availability of fuel for domestic and cottage industries coupled with the ever-rising prices of non-renewable energies in developing countries such as Nigeria have necessitated alternative energy sources. Briquette is a good example of an alternative source of energy. This is because briquettes are very cheap and affordable (Ogwu *et al.*, 2014). Briquettes are produced from biomass. Biomass is a natural material of biological origin in abundance. Its abundance in nature makes it the best alternative energy source which is good for the mitigation of greenhouse gas emissions (Abdu and Sadiq, 2014). Biomass is usually plant based and popularly called cellulosic biomass (Shukla, 2015). Therefore, different types of waste have been used to form biomass briquettes. Some of the briquettes formed are briquettes from sawdust, date palm trunk, different plastic wastes, groundnut shell, coffee husk and pulp, rice husk and several other biomasses (Onukak *et al.*, 2017). Over 40 years ago, researchers have looked towards the area of biomass for its renewability, abundance and positive environmental impacts. Felling of trees poses a serious danger to the environment which should be highly discouraged and room be given to other sources of renewable energy like agricultural waste materials (Mba, 2019, Olowoyeye, 2021). Biomass in its original state is hard to handle, transport, store and use because of its high moisture content, irregular shapes, irregular sizes and low bulk density. In order to resolve these challenges, densification is adopted. Densification involves the production of densified products having uniform shapes and sizes, making it easier to handle, store and to be transported easily. This brings about cost reduction (Kumar *et al.*, 2017). This research seeks to treat, characterize, torrefy Groundnut Shell and also to optimize the Calorific Value from produced Groundnut Shell Briquettes using Design Expert after which the performance evaluation was carried out.

2. MATERIALS AND METHODS/METHODOLOGY/EXPERIMENTAL PROCEDURE

2.1 Materials

The materials used are Groundnut Shell which was obtained from Somazhiko Gboko Local Government, Niger State. Cassava Starch was used as the binder.

2.2 Equipment

Briquettes Rig, Oxygen Bomb Calorimeter, Grinding Machine, stop watch, Measuring Cylinder and Analytical Balance.

2.3 Methods

2.3.1 Treatment and characterization of the raw material

The initial treatments of the agricultural waste (Groundnut Shell) were carried out through sorting, drying, size reduction. The sorted feedstock was sun dried for 14 days and then taken for characterization: Proximate and

Ultimate analyses.

2.3.2 Torrefaction of the treated Groundnut Shell

The agricultural wastes (Groundnut Shell) was torrefied at a temperature range of 240 – 260 °C using muffle oven for a period of an hour at NCRI Badeggi, Bida Niger State.

2.3.3 Optimization of the calorific value from produced briquettes using design expert

Design Expert Software was used for the optimization of the calorific value obtained from the briquettes which was produced from torrefied agricultural wastes. The Central Composite design (CCD), the experimental design in Response Surface Methodology (RSM) was used to obtain a second-order (quadratic) model. The design resulted in 20 Runs with Binder proportion, compaction pressure and dwelling time as independent variables and the Calorific Value of the briquettes as the response. Four replication of center points were used to predict a good estimation of errors and experiments were done in a randomized order. The actual and coded levels of each factor are shown in Table 1. The coded values were designated by -1 (Minimum), 0 (Centre) and +1 (Maximum) was used as adopted from (Ameh *et al.*, 2019).

Table 1 Factors for Central Composite Design for briquettes production

Factors	Units	-1	0	+1
Binding Ratio (A)	wt%	20	0	60
Dwelling Time (B)	Seconds	40	0	120
Compaction Pressure (C)	MPa	2	0	5

2.3.4. Determination of the Calorific Values of the produced Briquettes

The Calorific values of the produced briquettes (Groundnut Shell Briquettes) were determined by combusting the Briquettes with oxygen under pressure in a scaled bomb. The heat of the subsequent reaction was measured from the temperature rise of a surrounding water bath. By the calibration of the calorimeter system with thermochemical grade Benzoic Acid, the Gross Calorific value at constant volume was determined.

2.3.5 Briquetting of Pre-treated Samples

According to (Ameh *et al.*, 2019), a biomass mixture was prepared for briquettes production using a constant mass of biomass (Groundnut shells) of 70g and different concentration of binder; (20 to 60 wt.%), 145 ml of distilled water was used. Based on the design Expert used (CCD), twenty runs of briquettes of Groundnut Shells were also produced. Binders in form of paste were prepared using hot water of temperature 100°C (20 to 60 wt % binder + 145 ml of hot water). At the start of the production of the briquettes, a hot water starch binder in the form of paste was added to biomass (torrefied Groundnut shells), 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 dimensions of 11cm height and 7cm diameter. The mould was covered with a top plate and compressed manually at varying pressures of (2 – 5 MPa) and at varying dwelling time of (40 – 120 seconds) for briquette formation. The briquettes formed were sun dried for 14 days before further analyses.

2.3.6 Characterization of the Briquettes with optimum Calorific value

The following methods of analysis were used to characterize the briquettes:

Proximate and Ultimate analyses.

2.3.7 Thermal Analysis of the Produced Briquettes

The following analyses were carried out:

2.3.7.1 Burning rate

The burning rate was determined using insulated Biomass Stove, stopwatch and a fire source. Burning rate is the rate at which a known mass of briquette is allowed to burn completely in the presence of oxygen. The Briquette was placed in a biomass stove and lighted until it started burning. The time taken by the briquette to burn completely was recorded using the stopwatch as adopted by (Ameh *et al.*, 2019). The Burning Rate of the samples was determined using Eq. 1

$$\text{Burning Rate} = \frac{\text{Total weight of the burnt Briquettes}}{\text{Total time taken by the Briquettes}} \quad (1)$$

2.3.7.2 Ignition time

The ignition time was determined when a known mass of a briquette is ignited. This was determined using wire mesh grid, bursen burner and a fire source. The method used by (Onuegbu *et al.*, 2011) was adopted where 100 g of the Groundnut Shell briquettes was placed on a wire mesh grid in between two fire retardant bricks to allow free flow of air. A bursen burner was placed underneath the setup until the flame became blue. The burner was kept lighted until the briquettes were ignited. The ignition time was determined using Eq.2

$$\text{Ignition Time} = \text{Time the briquette is ignited} - \text{Time the burner was lighted} \quad (2)$$

2.3.7.3 Water Boiling Test

Water boiling test entails the time taken by a known mass of briquette to boil water. A biomass stove was loaded with a known mass of briquette and allow to heat water in a pot until it started boiling. The time taken by the briquettes to boil water was recorded according to (Yahaya and Ibrahim, 2012).

2.3.8 Evaluation of the produced briquette's performance

The produced briquettes were evaluated in order to examine its performance using biomass stove to cook. The Groundnut Shell Briquettes were used to cook a pot of food.

3. RESULTS AND DISCUSSION

The proximate analysis of the two samples (Groundnut Shell) is presented in the Table 2.

Table 2 Proximate Analysis of Groundnut shell

Samples	MC	AC	VM	FC
Groundnut Shell (%)	10.41	2.525	62.140	24.925

Table 2 indicates the percentage of moisture content, Ash content, volatile matter content and fixed carbon content. The table shows that Groundnut Shell volatile matter is quite high which implies that the combustion will be fast as well as the burning temperature. The groundnut shell has a very high fixed carbon content of 24.925% as compared to other agricultural wastes. This suggests that groundnut shells can be more exposed to solid combustion. This implies that groundnut shells will produce low amount of ash. This agrees with the findings of Chukwuneke *et al.* (2020)

The Ultimate analysis of the two samples (Groundnut Shell and Rice Husk) is presented in Table 2.

Table 3 Ultimate Analyses of Groundnut shell

Samples	C	H	N	O	S
Groundnut Shell (%)	62.337	5.920	1.892	27.328	0.275

Table 3 indicates the percentage of Carbon, Hydrogen, Nitrogen, Oxygen and Sulfur content. The amount of Carbon and Hydrogen content in the samples is very satisfactory as it signifies that the samples have high combustibility and can be used to produce briquettes.

3.1 Statistical and Optimization of the Calorific Value of Groundnut Shell Briquettes.

The design plan in Table 4 was employed for the statistical analysis and optimization of the calorific value of Groundnut Shell and Rice Husk Briquettes. The variables: Binding Ratio (A), Dwelling Time (B) and Compaction pressure (C) with Calorific value as the response were optimized using the coded values of the test variables.

Table 4 Results of Experimental Design Matrix for optimization of Calorific values for Groundnut Shell Briquettes

			F1	F2	F3	Response 1
Std	Run	Space Type	A: Binding Ratio	B: Dwelling Time	C: Compaction Pressure	Calorific Value
			Wt%	Seconds	MPa	MJ/kg
18	1	Center	40	80	3.5	18.7048
10	2	Axial	74	80	3.5	20.2376
11	3	Axial	40	40	3.5	15.5013
13	4	Center	40	80	3.5	18.6558
3	5	Factorial	20	120	2	17.7652
2	6	Factorial	60	40	2	19.2005
1	7	Factorial	20	40	2	12.9054

14	8	Axial	40	80	6	19.6422
5	9	Factorial	20	40	5	15.8764
20	10	Center	40	80	3.5	18.7048
15	11	Center	40	80	3.5	18.7048
7	12	Factorial	20	120	5	22.0926
6	13	Factorial	60	40	5	18.5959
19	14	Center	40	80	3.5	18.7048
17	15	Center	40	80	3.5	18.7048
12	16	Axial	40	147	3.5	18.9167
4	17	Factorial	60	120	2	18.5689
16	18	Center	40	80	3.5	18.7048
8	19	Factorial	60	120	5	18.5689
9	20	CentEdge	20	80	2	16.0987

The energy value depends on the significance of the variation of the results from process parameter combinations. The quadratic regression equation developed from the software is seen in Eq 3. This equation gives the optimum calorific value by relating it with the actual value.

$$y = -0.023911 + 0.268939A + 0.176056B + 1.74973C - 0.001834AB - 0.033082AC + 0.004085BC + 0.000396A^2 - 0.000506B^2 - 0.030206C^2 \quad (3)$$

where A = Binding Ratio; B = Dwelling Time; C = Compaction Pressure; Y = Calorific Value

The quadratic model shows how the three factors (A, B and C) affect the response (Calorific values). It comprises one-factor and multi-factor coefficients, which gives the effect of a single factor and combined effects of different factors respectively. The positive and negative terms represent synergistic and antagonistic effects respectively. In Table 4, the sequential model sum of squares gave a model F-value of 69.09 which implies that the model is significant. This level of significance justifies the fact that the proposed quadratic model is adequate. The Model is adequate since the statistic gave test of regression coefficient of $R^2 = 0.9842$ with adjusted R^2 value of 0.9699 and predicted R^2 value of 0.9071. The CV obtained was 1.83%. Since the Adeq Precision of 39.9650 is greater than 4, the signal is thus adequate; hence the design space can be navigated with the model (Chukwunke *et al.*, 2020). Using the 5% significance p-value level for the analysis of variance (ANOVA), it can be seen from Table 5 that the terms A, B, C (Linear), AB, AC (Interactive) and B^2 (quadratic). Fig 1 shows the combined effect of two independent variables on the Caloric Value as shown in the 3D surface plots. The interactive effect of dwelling time and binding ratio on the Caloric Value of Briquettes produced from Groundnut Shells shows that as the dwelling time and binding ratio increase, the calorific value also increases until it reaches the optimum point. The optimum point gives high quality briquettes according to the findings of Chukwunke *et al.* (2020).

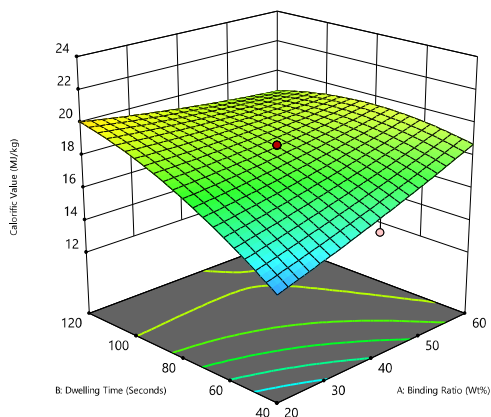


Fig. 1 Interaction effects of factors Dwelling Time and Binding Ratio

Fig 2 shows the perturbation plot where the dwelling time, binding ratio and compaction pressure influence the calorific value. Keeping the dwelling time (A) and the compaction pressure (B) constant, it was observed that as the binding ratio was increasing, the calorific value was also increasing but as soon as an optimum point was reached, the binding ratio started decreasing as well as the calorific value. This could be attributed to non-uniform

particle size of the treated groundnut shell used to produce the briquette which conforms to that of (Ameh *et al.*, 2019). Also, keeping the binding ratio and compaction pressure constant, it was observed that as the dwelling time was increasing, the calorific value was increasing. This implies that the longer the hydraulic jack presses the mixed sample, the better the calorific value. Finally, keeping the binding ratio and the dwelling time constant, the calorific values was observed to be increasing as the compaction pressure was increasing. This is a result of the particle size coming closer together to form a high quality briquette that can burn efficiently according to (Wilson *et al.*, 2017).

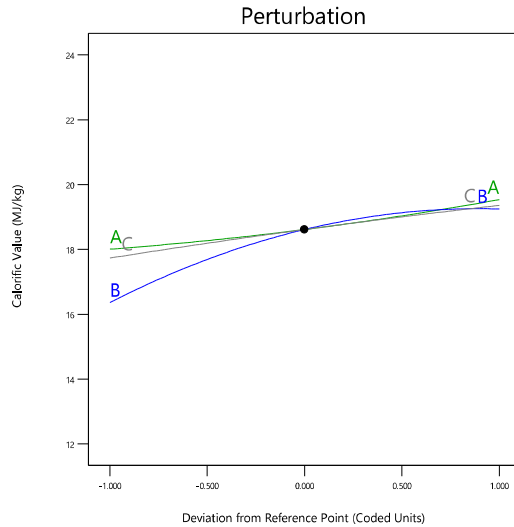


Fig 2 perturbation graphs showing the effects of the 3-factors on Calorific Value

Fig 3 shows the relationship between predicted energy value and actual energy value as given by the Design Expert software. Figure 3 gives a close distribution of the point along the straight line which implies agreement between the experimental and predicted energy values hence the developed quadratic model is justified.

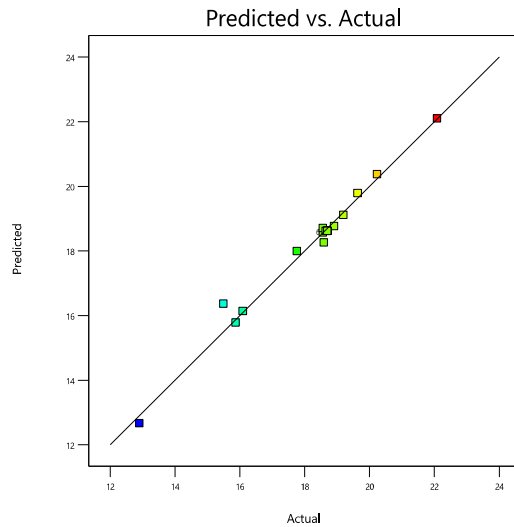


Figure 3 Graph showing the relationship between predicted values and actual values

Table 5. Significance of regression coefficients of Calorific value for Groundnut Shell briquettes

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	69.23	9	7.69	69.09	< 0.0001	significant
A-Binding Ratio	5.60	1	5.60	50.31	< 0.0001	
B-Dwelling Time	22.01	1	22.01	197.65	< 0.0001	
C-Compaction Pressure	6.37	1	6.37	57.25	< 0.0001	
AB	17.21	1	17.21	154.60	< 0.0001	
AC	8.53	1	8.53	76.63	< 0.0001	
BC	0.4807	1	0.4807	4.32	0.0644	
A ²	0.1996	1	0.1996	1.79	0.2102	
B ²	5.66	1	5.66	50.88	< 0.0001	
C ²	0.0351	1	0.0351	0.3156	0.5866	
Residual	1.11	10	0.1113			
Lack of Fit	1.11	4	0.2778	810.01	< 0.0001	significant
Pure Error	0.0021	6	0.0003			
Cor Total	70.35	19				

The optimization process gave 17.869 MJ/kg of Calorific Value, 39.525 wt% Binding Ratio, 57.512 Seconds dwelling time and 4.316 MPa Compaction Pressure. These optimum values are shown in Table 6.

Table 6. Optimum values of Groundnut Shell Briquettes obtained from Design Expert Software

Binding Ratio wt%	Dwelling Time (Sec)	Compaction Pressure (MPa)	Calorific Value (MJ/Kg)
A	B	C	
39.09	57.512	4.316	17.869

4. CONCLUSIONS

The Groundnut shell briquettes have shown to be good source of an alternative energy. This research work was carried out to analyze the energy content of the briquettes produced from locally sourced groundnut shell. The optimization of the calorific value of the groundnut shell briquettes using cassava starch as binder was performed using response surface methodology (RSM). The groundnut shell briquettes were produced using optimized condition of values of 39.525 wt% binding ratio, 57.512 seconds dwelling time, 4.316 MPa compaction pressure. This gave the calorific value of 17.869 MJ/kg, burning rate of 0.22 g/min, water boiling time of 15.82 mins and ignition time of 15 mins. This value of the calorific value falls within the range of 17.00 MJ/kg and 24.00 MJ/kg making it a good energy source.

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