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Production and Optimization of Briquettes from Sugarcane Bagasse using Blends of Waste Paper and Clay as Binders

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ABSTRACT: Demand for green environments has stimulated research on the migration from conventional to renewable energy sources. In the case of combustible energy for domestic applications, briquettes produced from biomass have proven to be a good replacement for wood fuel. In this study, investigation on the performance analysis and optimization of mix ratio of briquettes produced from sugarcane bagasse using composite binders (waste paper and clay) was carried out. Box-Behnken Design feature of the Design Expert software was employed for the optimization of the briquettes mix ratio. Briquettes were produced from sugarcane bagasse based on the optimum conditions of 9.12% clay, 12.57% waste paper, 78.31% proportion of sugarcane bagasse and 5 KN compaction pressure. The produced briquette was found to have a compressive strength of 6.4715 MPa and 0.857 g/min burning rate. The results of the study shows that the experimental values were close to the predicted values with a percentage error of 3.11% for compressive strength and1.79% for burning rate which confirms the validity and adequacy of the predicted models.

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Petroleum products, Coal and Natural Gas constitutes 80% of global conventional energy resources (Kpalo *et al.*, 2020). In Nigeria, the conventional energy resources and utilization shows that 51% of the total energy consumption are wood fuel such as twigs and charcoal, while other sources include natural gas 5.2%, hydroelectricity 3.1% and petroleum products 41.3% (Oyeleran *et al.*, 2015). Fear for depletion of the conventional energy couple with desire for green environments and threats of desertification, there is yearning desire for research in alternative renewable energy sources worldwide. Depending upon the needs for the energy, prominent among the renewable sources are wind, solar, biomass in the form of agricultural wastes and animal dung (Zubairu and Gana, 2014). In terms of combustible energy sources, biomass has wide acceptability as alternative source because of availability, ease of manipulation, affordability, compatibility and reduction to greenhouse gas emission when used as fuel (Ajimotan *et al.*, 2019). Biomass may be used directly as solid fuel for cooking or converted via a variety of technologies such as pyrolysis, gasification, combustion and biofuel production; hence biomass such as bagasse have turned to a promising alternative energy that will compliments the existing fossil fuel (Zubairu and Gana, 2014). Bagasse is one of the abundant biomass resources generated in Nigeria, it is a matted cellulose fiber residue from sugar cane that has been processed in a sugar mill or derived after the

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juice has been extracted. Previously, findings revealed that bagasse was burnt as a means of solid waste disposal. However, as the cost of fossil fuel increases and its related environmental impacts, bagasse has been regarded as fuel rather than refuse in the sugar mills (Aigbodion *et al.,* 2010). Many research works have been conducted on conversion of bagasse to useful product either as energy in the sugar mill, raw material for animal feed, bagasse briquette for cooking e.t.c. Ogwo *et a.l,* (2012) reported that 1 ton of sugarcane generates about 270 kilograms of bagasse with greater percentage of the bagasse generated being disposed and inefficiently utilized. More interest is being generated on the alternative uses of sugarcane as the impacts of global warming and deforestation become more and more evident. Bagasse has low energy and bulk density which makes it difficult to handle, transport and stored. To alleviate these draw backs, bagasse are compacted in the form of briquettes for use as alternative energy for cooking in order to produce homogeneous, uniformly sized solid pieces of high bulk density and energy making it easy to handle and transport (Kathuria, 2012). Kpalo *et al.* (2020) reported that briquette production involves a number of consecutive stages, broadly broken down into pretreatment, carbonization, binder addition and densification. Biomass carbonization before briquetting increases cohesion, which is achieved by low-pressure agglomeration with the use of binders (Lohri *et al.,* 2015). In addition, carbonization of the biomass before briquetting drives off the volatile compounds and moisture leaving a biochar with high proportion of carbon (Mohammed *et al.,* 2014). The effectiveness of briquettes depends on the quality of the binder used. Zhang *et al,* (2018) reported that different types of briquettes need different types of binder. Binders are introduced as part of the briquette composition to increase the strength and calorific value of the briquette (Manyuchi *et al.,* 2018). Different types of organic and inorganic binders have been used to bind and enhance the various characteristics of briquettes. Organic binders are mostly derived from biomass materials such as starch, waste paper and lignin liquor while inorganic binders are mostly clay, lime and kaolin (Olugbade *et al.,* 2019).

Briquettes production suffers draw backs with respect to determining appropriate composition of the constituents for effective combustion process. To overcome this short coming, this work produced and optimized briquettes from sugarcane bagasse using the blends of waste paper and clay as binders.

MATERIALS AND METHODS

Materials: The materials used are sugarcane bagasse as biomass material, waste paper and clay as binders. These materials were obtained around Bauchi state, Nigeria.

Raw Materials Preparation: The sugarcane bagasse were obtained around Bauchi metropolis, it was carefully screened, washed and sun dried to a moisture content of less than 18% before it was carbonize. The sugarcane bagasse was carbonized in a muffle furnace at a temperature of 300^0C for thirty minutes to obtain a carbonized bagasse; the carbonized bagasse was crushed using mortar and pestle. The clay soil collected was pulverized using a mortar pestle and sieve to a particle size of 0.5 mm. The clay was pulverized to increase the surface area of the components to enable thorough blending during bonding. The waste paper was shredded into small pieces; they were mixed together and soaked in cold water at room temperature for two days; the paper was converted to pulp by manual pounding with a mortar and pestle in accordance with a method adopted by Oyeleran *et al.,* (2015).

Experimental Design: Box-Behnken Design (BBD) feature of Design expert was employed; three independent variables or factors at three levels (-1, 0, +1) were considered. The factors are binder proportion, compaction pressure and proportion of sugarcane bagasse. The responses are burning rate and compressive strength. The values of the factors are presented in Table 1. Seventeen experimental runs were randomly generated based on the result obtained from the Box-Behnken designs presented in Table 2.

Briquetting Process: The briquette was formed in a cylindrical mold with a diameter of 8cm, a height of 7cm and a rod was placed at the center to create a hole in the center of the briquette which increases oxygen supply and porosity, thereby improving briquette combustion (Kpalo *et al*., 2020). Seventeen briquettes samples were produced based on the design of experiments values obtained in the design expert software as presented in Table 2. The resulting briquette produced were placed on a flat surface and air dried in a closed room for 14days before testing the responses.

Analysis of the Responses

Compressive strength: The compressive strength of the briquette was determined using 3000 kN Capacity Compressive Strength Machine in accordance with ASTM Standard D2166-85. The briquette was placed in between the plate of the machine and was subjected to uniform loading until failure or rupture (Kpalo *et al.,* 2020).

Table 1: Experimental Factors and Levels of Variables Considered for Briquette Productions

Factor	Units	Low	High
Binder proportion	%	5(-1)	15(+1)
Compaction pressure	KN	5(-1)	15(+1)
Proportion of sugarcane bagasse	%	70(-1)	80(+1)

Table 2: Box-Behnken Design for Three Independent Factors

S/No	Binder proportion (%)	Compaction pressure (KN)	Proportion of Bagasse (%)	Burning rate (g/min)	Compressive strength (MPa)
1	15	5	80	-	-
2	20	5	65	-	-
3	15	15	50	-	-
4	20	15	65	-	-
5	20	10	80	-	-
6	10	10	50	-	-
7	10	15	65	-	-
8	15	10	65	-	-
9	15	15	80	-	-
10	10	5	65	-	-
11	15	10	65	-	-
12	15	10	65	-	-
13	15	10	65	-	-
14	20	10	50	-	-
15	15	10	65	-	-
16	10	10	80	-	-
17	15	5	50	-	-

Burning rate: The burning rate is the rate at which certain mass of the briquette fuel is burn in air. A briquette sample of known mass was placed on a metal can, the briquettes were ignited and the weight of the set up was periodically measured and recorded throughout the combustion process using a stop watch.

The briquette burning rate was evaluated using equation (1) as reported by (Arewa *et al.*, 2016).

$$BR = \frac{Q1-Q2}{T} \quad \dots (1)$$

Where B_R is the burning rate (g/min), Q_1 is the initial briquette weight (g), Q_2 is the final briquette weight after burning (g) and T is the total burning time.

RESULTS AND DISCUSSIONS

Briquette Production: The briquette was produced according to the design matrix obtained from design expert software. The responses were measured and the results are presented in Table 3.

Statistical Analysis: The experimental results obtained from the Box-Behnken Design are presented in Table 3 above. From the Fit Summary it is observed that the quadratic model was best for the briquette production process. Analyzing the statistical results for the briquette produced, ANOVA and model fitting results of the experimental data from Table 4 and 5, it can be seen that compaction pressure and binder proportion has the strongest impact on compressive strength with (p-value <0.0001) and burning rate (p-value <0.0004).

Table 3: Experimental Design Matrix as Generated By Design of Experiment Software and the Responses Obtained

Run	Binder proportion (%)	Compaction pressure (KN)	Proportion of Bagasse (%)	Burning rate (g/min)	Compressive strength (MPa)
1	15	5	80	0.596	2.864
2	20	5	65	1.100	2.546
3	15	15	50	0.579	2.228
4	20	15	65	0.742	2.864
5	20	10	80	0.794	2.864
6	10	10	50	0.741	1.910
7	10	15	65	0.740	4.137
8	15	10	65	0.875	5.411
9	15	15	80	0.637	7.002
10	10	5	65	0.782	2.864
11	15	10	65	0.583	7.320
12	15	10	65	1.057	6.684
13	15	10	65	0.844	3.501
14	20	10	50	0.760	7.320
15	15	10	65	0.665	4.137
16	10	10	80	0.787	3.819
17	15	5	50	0.789	2.546

Model equations were developed to represent the responses which are compressive strength and burning rate as a function of Binder Proportion (A), Proportion of Sugarcane Bagasse (B), and Compaction Pressure (C). The coded equations are presented in equations 2&3;

Compressive strength = +80.8605 - 0.01805A - 2.1985B + 0.6789C - 0.00274AB … (2)
+ 0.01246AC - 0.0147BC + 0.0003A^2 + 0.01654B^2 + 0.00152C^2

Burning Rate = -35.4938 + 0.110137A+ 0.939920B + 0.100768C - 0.003375AB … (3)
+ 0.005940AC - 0.003011BC + 0.003845A^2 - 0.005846B^2 + 0.003439C^2

In the polynomial model obtained in equation 2 and 3, the positive and negative coefficients indicate synergistic and antagonistic effects of the factors (A, B and C) respectively. Equations 2 and 3 show the adequacy of the quadratic models which were statistically significant with F-values of 85.0 for compressive strength and F-value of 18.20 for burning rate. From Table 5, it could be observed that the interactive terms (AB, AC, &BC) and quadratic terms (A^2, B^2& C^2) are significant since their values are less than 0.05. The 'Lack of Fit' value for the compressive strength and burning rate are 0.573 and 0.6241 respectively were not significant which is desirable. The adequacy of the model was further established by the determination of regression coefficients (R^2).

Table 4: Analysis of Variance of the Developed Compressive Strength Quadratic Model

Source	**Sum of squares**	**df**	**Mean square**	**F-value**	**p-value**
Model	20.18	9	2.24	85.09	<0.0001 significant
A	1.73	1	1.73	65.70	<0.0001
B	2.34	1	2.34	88.67	<0.0001
C	14.43	1	14.43	547.45	<0.0001
AB	0.0188	1	0.0188	0.7121	0.4266
AC	0.3881	1	0.3881	14.73	0.0064
BC	0.5402	1	0.5402	20.50	0.0027
A^2	0.0002	1	0.0002	0.0090	0.9271
B^2	0.7199	1	0.7199	27.31	0.012
C^2	0.0061	1	0.0061	0.2307	0.6457
Residual	0.1845	7	0.0264		
Lack of Fit	0.1512	3	0.0504	6.05	0.573 not significant
Pure Error	0.0333	4	0.0083		
Cor Total	20.37	16			

P-values less than 0.05 indicate that the model terms are significant, from Table 4 it could be observed that the linear terms (A, B, C) interactive terms (AC, BC) and quadratic terms (B2) are significant.

Table 5: Analysis of Variance of the Developed Burning Rate Quadratic Model

Source	**Sum of squares**	**df**	**Mean square**	**F-value**	**p-value**
Model	0.3027	9	0.0336	18.82	0.0004 significant
A	0.0089	1	0.0089	5.01	0.0603
B	0.0001	1	0.0001	0.0790	0.7868
C	0.0020	1	0.0020	1.09	0.3309
AB	0.0285	1	0.0285	15.94	0.0052
AC	0.0882	1	0.0882	49.36	0.0002
BC	0.0227	1	0.0227	12.68	0.0092
A^2	0.0389	1	0.0389	21.77	0.0023
B^2	0.0899	1	0.0899	50.33	0.0002
C^2	0.0311	1	0.0311	17.42	0.0042
Residual	0.0125	7	0.018		
Lack of Fit	0.0041	3	0.0014	0.6482	0.6241 not significant
Pure Error	0.0084	4	0.0021		
Cor Total	0.3152	16			

Table 6: R^2 Statistics for the Regression Model

Response	R^2	**Adj** R^2	**Pred** R^2	**Adq Pre**	**Std Dev**	**Mean**	**C.V%**	**PRESS**
Compressive Strength	0.9909	0.9793	0.8787	33.3593	0.1623	4.18	3.88	2.47
Burning Rate	0.9603	0.9093	0.7505	16.0528	0.0423	0.7753	5.45	0.0786

The R^2 value of compressive strength and burning rate (0.9909 and 0.9603) were very close to unity indicating that the regression models were good fits for the experimental data. For the compressive strength the R^2 value indicates that the model can explain 99.09% of the data variations, only 0.91% of the total variations were not explained by the model, while for the burning rate the model can explain 96.03% of the data variations, and only 3.97% of the variations were not explained by the model. According to Lee Man *et al.* (2010), for a model to be considered accurate, the R^2 value should not be less than 0.75. The values of Adj $R^2$for compressive strength and burning rate which are (0.9793 and 0.9093) indicate that the models were highly significant, which also indicates a good agreement between the predicted and experimental values of compressive strength and burning rate. According to Manase *et al.* (2012), the Adj R^2 **(**which measures the amount of variation about the mean explained by the model) and the Pred R^2 (which is a measure of how good the model predicts the response value) should be within 20% i.e less than 0.2 to be in good agreement. This study satisfied the requirement with a Predicted R^2 value of 0.8787 and 0.7505 for compressive strength and burning rate respectively. The low value of standard deviation 0.1623 and 0.0423 for compressive strength and burning rate indicates that the responses are close to the mean which further validates the model.

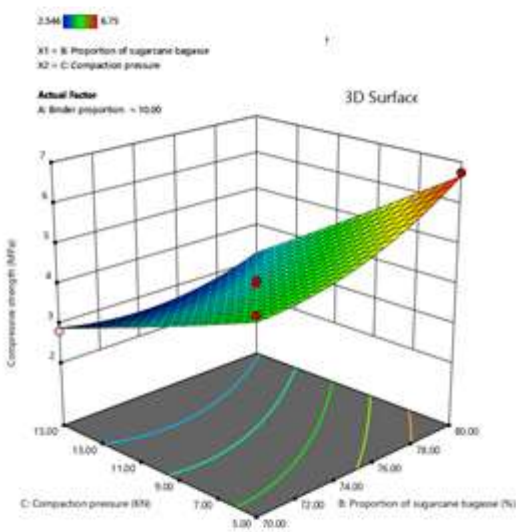

Fig 1: Effects of Compaction Pressure and Proportion of Sugarcane Bagasse on Compressive strength

The coefficients of variation, C.V of 3.88 and 5.45 for compressive strength and burning rate, respectively shows a good precision of experimental values. PRESS (predicted residual error sum of squares) explains how the variation of the dependent variable in a regression model cannot be explained by the model. Generally, a lower PRESS indicates that the model can better explain the data while a higher PRESS indicates that the model poorly explains the data. The low value of PRESS for compressive strength 2.47 and 0.0786 for burning rate indicates that the model can predicts future responses effectively. Figure 1, 2 and 3 presents the three-dimensional plot that represents the process variables affecting the responses.

Figure 1 shows the effects of compaction pressure and proportion of sugarcane bagasse on compressive strength. From the plot, it could be observed that compressive strength increases as compaction pressure and proportion of sugarcane bagasse increases. This change could be as a result of increase in the compaction pressure which conforms to findings of Chukwuneke *et al.* (2020), where increase in the compaction pressure was reported to increase the compressive strength of the briquette.

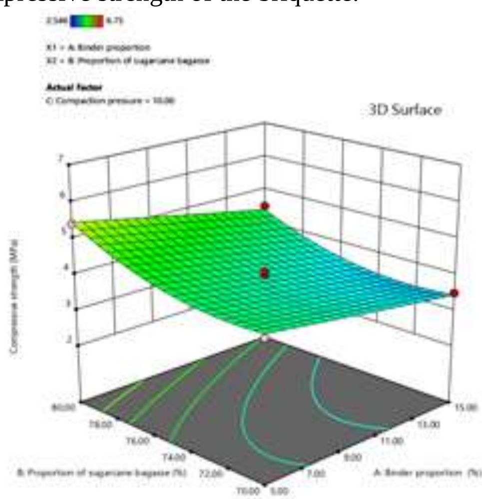

Fig 2: Effects of Binder Proportion and Proportion of Sugarcane Bagasse on Compressive strength**.**

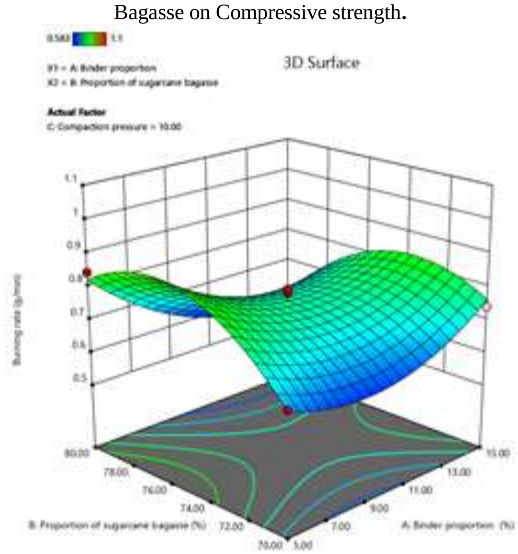

Fig 3: Effects of Binder Proportion and Proportion of Sugarcane Bagasse on Burning Rate

Figure 2 shows the effects of binder proportion and proportion of sugarcane bagasse on compressive strength. From the plot, at 5% binder proportion and 80% proportion of sugarcane bagasse the compressive strength increases to 5.41 MPa. This means that high proportion of sugarcane bagasse leads to increase in the compressive strength, In addition, smaller particle size of the carbonized sugarcane bagasse increases the compressive strength of the briquette. This is in consistent with Chukwuneka *et al.,* (2020) in stating that increase in the proportion of biomass increases the compressive strength of the briquette.

Figure 3 shows the effects of binder proportion and proportion of sugarcane bagasse on burning rate. From the plot, it could be observed that as the binder proportion increases, the burning rate also increases, which indicates that clay and waste paper binder has significant effects on burning rate. This is contrary to the findings of Hassan *et al.,* (2017) where they reported that a carbonized material blended with waste paper increases the burning rate and thermal conductivity of the briquettes.

Numerical Optimization: Since optimal conditions of response differ to the other, therefore it is crucial to optimize the criteria that will be favorable for the responses.

Table 7: Numerical Optimization Constraints for Briquettes Production

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
A: Binder proportion	Maximize	5	15	1	1	5
B: Proportion of sugarcane bagasse	is in range	70	80	1	1	3
C: Compaction pressure	Minimize	5	15	1	1	3
Compressive strength	Maximize	2.546	6.75	1	1	5
Burning rate	Maximize	0.583	1.1	1	1	5

The optimal condition for the production of briquette was obtained by solving the regression equation using the design expert software. The optimum conditions obtained from this study were as follows; binder proportion of 9.128% clay, 12.57% waste paper, and 78.307 % proportion of sugarcane bagasse and 5 KN compaction pressure. At these optimum conditions, the responses obtained were 6.274 MPa for compressive strength and 0.857 g/min for burning rate with a desirability value of 0.634. The value obtained for the compressive strength (6.227 MPa) is within the ASTM standard (a minimum of 1.0 MPa) specified for all types of briquette. A similar value of 1.02 Mpa and 8.32 MPA was obtained from con corbs briquette produced by Arinsola *et al.* (2019). The higher value of compressive strength obtained in this study is as a result of the paper pulp used as a binder which tends to increase the compressive strength of the briquette. However, high compressive strength of the briquette makes it safer to store, transport and will not wear off easily (Kpalo *et al.* (2020).The Burning rate is the rate at which a certain mass of briquette burn in air. The burning rate value obtained in this study is 0.827 g/min. Abdulkareem *et al.* (2018) study the combustion characteristics of biodegradable biomass briquette and obtained a burning rate of 0.4386 g/min and 0.5173 g/min which is lower than the value obtained in this study; also Arewa *et al.* (2016) obtained a similar value of 1.764 and 1.96 g/min as burning rate of rice husk with cassava starch and cassava peels as binders. The low burning rate obtained in this study is of great advantage compared to the value obtained by Arewa et *al.,* (2016). This implies that the briquettes will not burn-out rapidly, and hence, it continues to generate more energy for a longer period of time.

Table 8: Validation of Experimental Results

Response	Predicted Mean	Predicted Median	Std Dev	N	SE Pred	95% PI low	Data Mean	95% PI high	%Error
Compressive strength	6.2764	6.2764	0.1623	3	0.1466	5.9297	6.4713	6.6231	3.115
Burning rate	0.8567	0.8567	0.0422	3	0.0382	0.7665	0.8723	0.9470	1.785

Validation of Experimental Results: The model equations for the prediction of the optimum response value were validated using the optimal conditions suggested by Box-Behnken Design. From Table 8, the experimental values were close to the predicted value hence it confirms the validity and adequacy of the predicted models. Under optimum conditions with 9.12% clay, 12.57% waste paper, 78.31% proportion of sugarcane bagasse and 5 KN compaction pressure the standard deviation for compressive strength and burning rate are 0.1623 and 0.0423 which are close to the predicted values and the percentage error of 3.115 and 1.785% was obtained for compressive strength and burning rate respectively.

*Conclusions***:** The objective of this study was to optimize the biomass to binder ratio used for the production of sugarcane bagasse briquette. The optimization was done using Box-behnken design tool (BBD) and the optimum conditions of the biomass to binder ratio was obtained, after which a sugarcane bagasse briquette was produced from the optimum conditions. The resulting physical parameters analyzed (compressive strength and burning rate) proves the effectiveness of the briquette produced as a replacement for wood fuel that would be more adaptable for domestic application.

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