

OPTIMIZATION OF CALORIFIC VALUE OF BRIQUETTES FROM MIXTURE OF RICE HUSK AND SAWDUST BIOMASS USING TAGUCHI APPROACH

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ABSTRACT

Briquettes from biomass with higher calorific value is important towards the production of eco-friendly solid fuels. This study focuses on the optimization of calorific value of briquettes made from mixture of rice husk and sawdust biomass using Taguchi method. The rice husk and sawdust biomass were dried and carbonized in a muffle furnace at temperature of 270°C for an average of 20 mins. The carbonized feedstocks were sieved into 0.6, 0.8 and 1.0 mm particle sizes and further briquetted at 90:10, 80:20, 70:30 rice husk to sawdust mixing ratio and using 3 MPa, 4 MPa and 5 MPa compacting pressure. The result of the analysis showed that the effects of particle size, compacting pressure and mixing ratio on the calorific value were ranked 1, 2 and 3 in the order of effect. The optimal design gave a calorific value of 22826 J/g which represents a 27.76% increase relative to the worst original design of 17867 J/g. The use of catalyst during carbonization is recommended to improve the quality of better eco-friendly bio fuel briquettes.

Keywords: Optimization, Carbonization, Briquettes, Calorific value, Particle size, Mixing ratio, Compaction pressure. Taguchi Method, Minitab 18, Biomass.

1 INTRODUCTION

The environmental impacts associated with burning of fossil fuels from agro-industrial and industrial process is the bane of global environmental challenges today. However, briquetting of biomass provides an alternative energy resource which enhances sustainable development. For example, reports have shown that as at 2016, 97.1 million metric tons of CO₂ was emitted which arose from the burning of fossil fuels [1, 2]. This trend in global climate change calls for a shift from fossil fuel to renewable energy resources to reduce the CO₂ emission. This will help salvage our degrading environment, ensure sustainable development and complement energy resources. Over 70% Nigerians live in the rural areas and solely depend on agricultural biomass, fuel wood and charcoal for their domestic energy needs [3]. Recently, Nigeria ranked second in the World in fuel wood consumption by households at 177, 996m³ equivalents to 428, 352. 714 tonnes and a world share of 10.1% as stated by [4]. Unfortunately, the demand for fuel wood is expected to rise to about 213.4x10³ metric tonnes, while its availability may decrease to 28.4x10³ metric tonnes by 2030 [5, 6].

However, rice husk, a potential source of domestic fuel for fuel is less harnessed [7]. According to [8], Nigeria is the largest producer of paddy in Africa with 7.2 million metric tonnes produced in 2018 and up to 7.4 million metric tonnes by 2019 and 2020 [9], while global production of rice was estimated at 633 million tonnes. Rice husk is the outer layer of rice seed, removed as a by-product during milling. It is estimated that for every four tonnes of rice milled about 1 tonne of rice husk is generated [10]. Therefore, about 1.8 million metric tonnes of rice husks were produced in Nigeria alone in the year 2018 [8]. Thus, the rice industry generates large amount of biomass in form of rice straw, rice husk and rice husk ash. Rice husks contains a high amount of silica limiting its disposal and slow decomposition in the soil [11, 12]. The population surge in Nigeria has culminated in the high demand for energy thereby having great impact on the economy and environment. Today most people rely solely on kerosene or LPG as their domestic energy source [5]. Undoubtedly, there is an urgent need for

alternative energy resources to complement petroleum products and preserve our forest resources and by extension the environment.

Briquetting is a mechanical compaction process for increasing the density of bulky materials. It can be regarded as a waste control measure in the case of production of briquettes from agricultural biomass. Briquettes can be used to provide fuel source as a preventive measure to ecological challenges. There are a number of indigenous materials found to be suitable for briquetting into fuel. These include; rice husk, water hyacinth, sawdust cowpea chaffs and corn cobs etc. [13, 14, 15]. Densification of biomass residue is to increase the bulk density of a given material; this is achieved by the application of pressure to produce homogenous, uniformly sized solid pieces of high bulk density which can be used conveniently as fuel [16, 17]. The briquetting of agricultural biomass is achieved by direct briquetting of agricultural biomass using additives (binders such as starch and gum arabic) carbonization using binders and binder less briquetting. In practice, briquettes made from various types of agro residue can be used as fuel without carbonization or torrefaction. But these kinds of briquettes have been characterized by increased generation of smoke, low heat value, reduced ignition and burning properties and ultimately not stable under wet condition [18].

In the last four decades, researchers have focused on renewable energy resources to meet the ever increasing energy demand, allaying the over dependence on petroleum. This include the use of briquettes from biomass [3, 7]. However, previous researches have not considered the optimization of calorific value of briquettes considering parameters such as mixing ratio, particle size and compaction pressure. The use of Taguchi methodology for design of experiment considerably reduces experimentation time, improve product quality and ultimately save cost contrary to the one factor at a time (OFAT) method. For example, with three factors, each with three levels, the full factorial design would require $3^3 = 27$ possible combinations of trials. Taguchi method is a statistical optimization tool developed by Genichi Taguchi. It is a design of experiment of (DOE) approach to improve the quality of manufactured products by allowing the effects of several factors to be determined simultaneously [19]. In addition, the Taguchi method helps to determine the best combination of processing parameters/control factors required to obtain the optimum mixture composition for the rice husk and sawdust briquettes with maximal calorific value. This research is aimed at optimizing the caloric values of briquette using the Taguchi Statistical Optimization technique.

2 EXPERIMENTAL PROCEDURE

In this study, briquettes were produced from rice husk and sawdust sourced locally. These biomasses were sun dried between 4-6 days and was carbonized using a muffle furnace at temperature of 270°C [17]. The carbonized biomass was further sieved into various particle sizes of 0.6, 0.8 and 1.0mm according to procedure highlighted in ASAE S 424.1 (2003) and then followed by the standardized procedure for determining the bulk component that makes up a fuel such as moisture content (ASTM D3173), ash content (ASTM D3174), volatile matter (ATM D3175) and fixed carbon (ASTM D5373).

The experiment was conducted with three controllable three-level processing parameters namely; particle size, mixing ratio and compaction pressure. The biomass briquettes were formulated using different ratios of rice husk and sawdust. The ratio of rice husk to sawdust are 90:10, 80:20 and 70:30 with 16% by weight of the biomass as the binder weight which was gelatinized [21, 22]. A simple manual briquetting rig was fabricated and used at a compaction pressure of up to 3 MPa, 4 MPa, and 5 MPa for five minutes [23]. Briquettes was produced by mixing the carbonized feedstock (rice husk and sawdust) with the gelatinized tapioca starch as binder in the ratio's stated above. The product is collected from the press and dried.

2.1 Investigating the effect of process factors on the caloric value using Taguchi Method

To investigate the effect of particle size, mixing ratio and compaction pressure on the calorific value of the briquettes produced, three levels were assigned; 1, 2 and 3 which represent low, intermediate and high level respectively. These control factors and levels are presented in Table 1.

Table 1. Control factors and levels

Control Factor	Units	Level 1	Level 2	Level 3
A – Particle Size (PS)	mm	0.6	0.8	1.0
B – Mixing ratio (MR)	%	0.7	0.8	0.9
C – Compaction Pressure (CP)	MPa	3.0	4.0	5.0

The Taguchi method designs an orthogonal array (OA) to simplify the large number of experiments and assign them into a smaller number of trials to run the experiment. OA is an arrangement of numbers in columns and rows in a manner that each column represent a factor while the rows stand for levels of the factors [23]. In this study, three control factors, each with three levels, were considered, i.e. 3^3 (L_9 (3^3)) OA amounting to nine experimental runs with varied composition. Taguchi OA L_9 is shown in Table 2.

Table 2. Taguchi Orthogonal Array L_9

Experiment number	Factors and level			Parameter
	A	B	C	
1	1	1	1	A1B1C1
2	1	2	2	A1B2C2
3	1	3	3	A1B3C3
4	2	1	2	A2B1C2
5	2	2	3	A2B2C3
6	2	3	1	A2B3C1
7	3	1	3	A3B1C3
8	3	2	1	A3B2C1
9	3	3	2	A3B3C2

The different briquetting parameter combinations generated from the Taguchi design are shown in Table 3.

Table 3. Taguchi design OA L_9 showing details of Briquetting Parameter Combinations.

No. of Experiment	A Particle size (mm)	B Mixing ratio (%)	C Compaction Pressure (MPa)	Parameter setting
1	1 (0.6)	1 (0.7)	1 (3.0)	A1B1C1
2	1 (0.6)	2 (0.8)	2 (4.0)	A1B2C2
3	1 (0.6)	3 (0.9)	3 (5.0)	A1B3C3
4	2 (0.8)	1 (0.7)	2 (4.0)	A2B1C2
5	2 (0.8)	2 (0.8)	3 (5.0)	A2B2C3
6	2 (0.8)	3 (0.9)	1 (3.0)	A2B3C1
7	3 (1.0)	1 (0.7)	3 (5.0)	A3B1C3
8	3 (1.0)	2 (0.8)	1 (3.0)	A3B2C1
9	3 (1.0)	3 (0.9)	2 (4.0)	A3B3C2

2.2 Determination of caloric values

The 60 mm x 60 mm biomass briquettes (Plate 1) produced from the parameter setting was dried for 5 days. The calorific value of the dried briquettes was determined using an oxygen bomb calorimeter (GDY-1A+) in accordance with GB/T213. The calorific value obtained was analyzed by adopting the Larger- the –better signal-to –noise (S/N) ratio using Minitab 18 software in order to determine the optimal processing parameter required to produce briquettes with good calorific value and to establish the effects of each processing parameters on the calorific value of the briquettes (response).



Plate 1. 60 mm x 60 mm Briquette Samples

In the study of fuel properties better calorific value is usually desired. Hence, the objective of this research is to maximize the calorific value (CV) of the briquettes. Maximization of calorific value seeks to make the system response as large as possible by obtaining the larger-the-better signal-to-noise ratio (S/N). The process of operation is consistent with the highest S/N ratio always yields optimal quality characteristic with minimum variance [20]. The S/N ratio which corresponds to the larger-the-better quality characteristic was used in the analysis and is stated by Equation (1).

$$S/N_L = -10 \log \left(\frac{1}{n} \sum_{i=1}^n \frac{1}{y_i^2} \right) \tag{1}$$

Where y_i is the i th value of the quality characteristics and n is the number of values. In this case, the value of the quality characteristics is taken to be $y = Cv$. Besides, since numerical analysis does not create data variations, then $n = 1$ [24].

Hence, the equation of the signal-to-noise ratio becomes Equation (2).

$$\frac{S}{N_L} = 10 \text{Log} \left[\frac{1}{(Cv)^2} \right] \tag{2}$$

In this analysis, the level of the control factor with the larger S/N ratio implies that this level can have a larger calorific value (Cv). By choosing the level with the larger S/N ratio for each control factor, the estimation of the set of optimal levels of the control parameters for the briquetting is experimented. A confirmatory test of the selected control parameters setting is carried out to determine the optimal parameter settings.

2.3 Evaluation of Mean of S/N_L Ratio, Main Effect of Control Factors and the Rank of Effect.

The mean response for S/N_L ratio of each factor was investigated to determine the effect of mixing ratio, particle size and compaction pressure to the significance of the calorific value.

The mean of S/N_L ratio j_i (which represented the factor average effect at each level) was obtained by applying the expression for determining average of S/N ratio for each factor [20] as shown in Equation (3).

$$\bar{J} = \frac{1}{n} \sum_{j_i}^n = 1j_i | \forall_{j,i} \tag{3}$$

The effect of each factor E_j (mixing ratio, particle size and compaction pressure) is obtained by the difference between the maximum S/N_L ratio and the minimum S/N_L ratio at different factor levels this is shown in Equation (4).

The rank was estimated based on the magnitude of the effect of each factor.

$$E_j = F_{j \max} - F_{j \min} | \forall_i \tag{4}$$

Where: E_j is the effect of factors j , $F_{j \max}$ and $F_{j \min}$ are maximum and minimum value of factors j respectively. The sign $|_i$ indicates that Equation (4) was evaluated across the level.

3 RESULTS AND DISCUSSION

3.1 Proximate and Ultimate Analysis

The result of proximate and ultimate analysis is shown in Table 4. It can be observed that the moisture content of the rice husk reduced from 10.36% to 4.83% after carbonization. The ash content in briquettes normally cause increase in combustion remnant in the form of ash which lowers the heating value of briquettes, low ash content offer higher heating value for briquettes [25]. Other elemental compositions determined by the ultimate analysis are carbon 44.87% and 27.13% for carbonized rice husk and raw rice husk respectively, Nitrogen; 0.56% and 1.26% for carbonized rice husk and rice husk dry basis respectively. Similarly, carbonized sawdust had 0.85% nitrogen and 0.92% nitrogen sawdust dry basis. It was also observed that the fixed carbon content of sawdust increased from 14.07% to 51.16% after carbonization. This investigation has identified that the rice husk and sawdust sourced locally is comparable with other types of biomass therefore making it a good source of fuel for biomass briquetting.

Table 4. Proximate and Ultimate Analysis

Sample	Moisture content %	Nitrogen %	Ash %	Crude Fibre %	Volatile matter %	Fixed carbon (%)
Rice husk	10.36	1.26	26.41	38.20	56.10	27.13
Saw dust	8.35	0.92	1.51	45.30	76.89	14.07
Carbonized Rice husk	4.83	0.56	14.30	18.30	36.00	44.87
Carbonized sawdust	6.44	0.85	12.65	18.80	29.75	51.16

3.2 Effect of biomass type on caloric value

Plate 1 presents the briquettes made from carbonized rice husk and sawdust at various mixing ratios. The chart of calorific value (J/g) test result for nine experimental runs is presented in Figure 1. It was observed that experiment number 5 showed the highest calorific value at 22337 J/g compared to all other experimental runs. Similarly, the briquette produced from experiment 7 displayed the least calorific value of 17867 J/g compared to others; this showed that the parameter setting in experiment number 7 (17867 J/g) is the worst design compared to others.

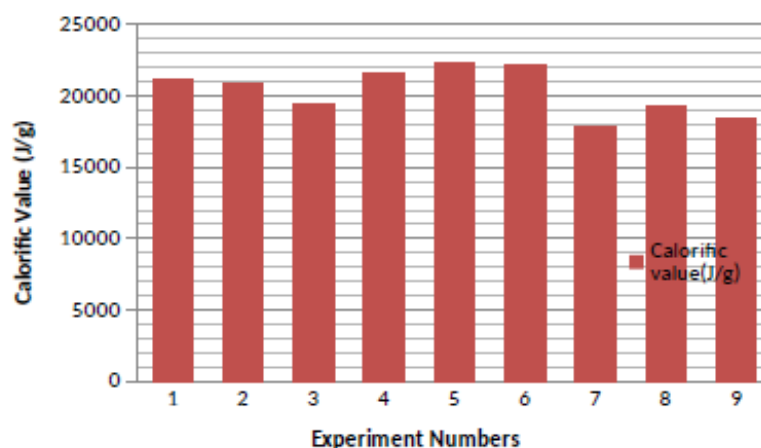


Figure 1. Plot of calorific value result for each parameter settings experimental run

3.3 Main effect of the control factors on calorific value

In this research, the optimum calorific value (J/g) of produced briquettes is desired from the experimental runs, this was analyzed using the S/N_L ratio which corresponds to the larger and better quality characteristics and were computed using Minitab 18. Figure 2 shows the graph of main effect

plot for mean which was plotted to find the optimum levels of particle size, mixing ratio and compaction pressure required to produce briquettes of optimum calorific value (J/g).

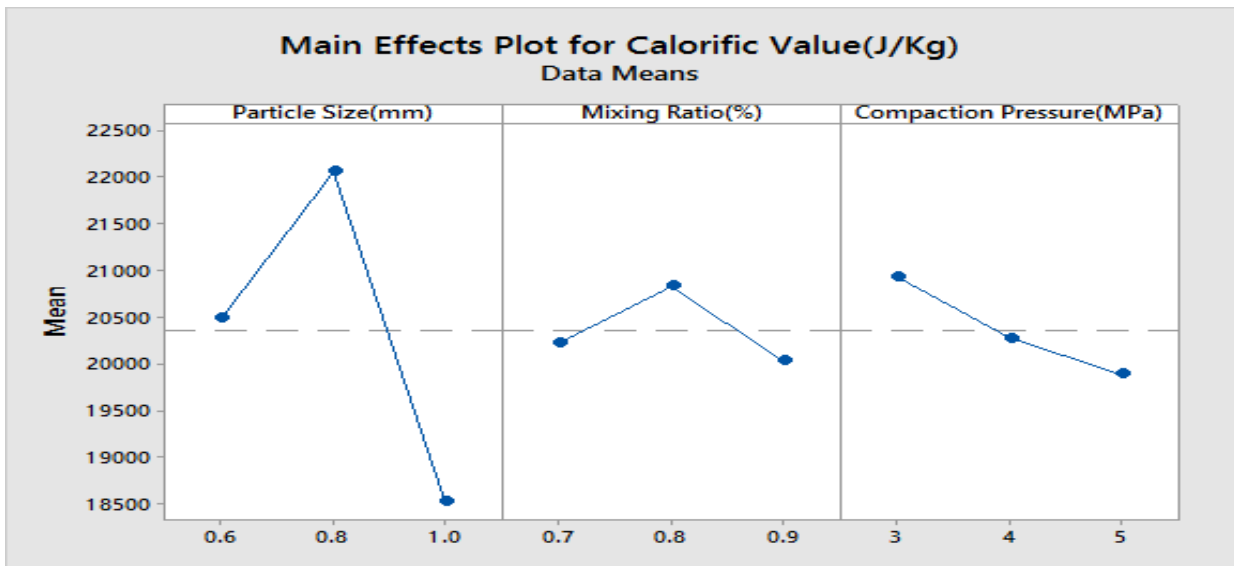


Figure 2. Main Effect Plot of Particle Size, Mixing Ratio and Compaction pressure

It was observed that an increment in the particle size led to the optimum increase in the calorific value up to 0.8 mm, however, there was a steep decline in the calorific value from 0.8 mm as shown in Table 5. Similarly, an increment in the mixing proportion resulted in higher calorific value (J/g), however at a mixing ratio of 0.9%, it was observed that the calorific value (J/g) decreased. Also, the calorific value (J/g) increased with decreasing compaction force.

Table 5. Experimental Results and S/N ratio

Experimental number	A Particle size (mm)	B Mixing ratio (%)	C Compaction pressure (MPa)	Response Calorific Value (J/g)	Signal-to-Noise ratio (S/N)
1	0.6	0.7	3.0	21201	86.5271
2	0.6	0.8	4.0	20822	86.3707
3	0.6	0.9	5.0	19467	85.7860
4	0.8	0.7	4.0	21608	86.6926
5	0.8	0.8	5.0	22337	86.9808
6	0.8	0.9	3.0	22236	86.9411
7	1.0	0.7	5.0	17867	85.0410
8	1.0	0.8	3.0	19348	85.7327
9	1.0	0.9	4.0	18392	85.2928

3.4 Optimum Parameter Setting of the Produced Briquette

From Table 6, the optimum processing parameters for the briquettes calorific value (J/g) is factor A (particle size, mm) as it showed the largest effect and ranked 1st, factor C (compaction pressure, MPa) is of penultimate significant effect and ranked 2nd while factor B (mixing ratio, %) had the least significant effect and therefore ranked 3rd. However, the optimal parameter setting from Table 6 is deduced thus; A1B3C2 which explains that the briquette should be produced from a combination of 0.6mm particle size, 90:30 rice husk to sawdust mixing ratio and 4 MPa compaction pressure as corroborated by the result of Okeyinka *et al.* [20] and Zarmai *et al.* [24]

Table 6. S/N_L response and rank

	Factor and Level		
	A	B	C
Level 1	86.2279	86.0869	86.4003
Level 2	86.8715	86.3614	86.1187
Level 3	85.3555	86.006	85.9359
Effect	1.516	0.3548	0.4644
Rank	1	3	2

3.5 Confirmatory Test

The calorific value of briquette from the optimal parameter setting was determined, analyzed and presented in Table 7.

Table 7. Comparison of Calorific Value in Worst Original and Optimal Designs

	Factors and Level			Cv (J/g)	S/N
	A	B	C		
Worst Original design	3	1	3	17867	85.0410
Optimal design	1	3	2	22826	87.1686
Increase %				27.76%	

From the experimental result, the optimal parameter setting gave the highest calorific value (J/g) compared to the results obtained from the nine experimental runs, relative to the worst parameter setting (A3B1C3) it was deduced that the optimum parameter setting (A1B3C2) maximized the calorific value (J/g) of the briquettes by 27.76%. Furthermore, optimal calorific value (22826 J/g) of the composite briquette produced was seen to be higher than those analyzed by [10]. This is to the fact that composites of rice husk and sawdust have higher fixed carbon content than those used in their study.

4 CONCLUSION

The optimization of calorific value from mixture of rice husk and sawdust biomass using Taguchi method was carried out. Out of the three control parameter, particle size (mm) had the most significant effect on the calorific value hence ranked 1st; the mixing ratio had the least effect and is ranked 3 on its effect on the calorific value (J/g). The optimal parameter setting of 0.6mm particle size, 90:10 rice husk to sawdust mixing proportion and 4MPa compacting pressure produced briquettes with good combustion property of 22826 J/g that can be used as alternative source of renewable fuel which is eco-friendly since it burns with very little or no smoke.

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