Optimization of Process Conditions for Briquette Production From Rice Husk and Saw Dust

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Abstract: This study investigated the optimization of the process parameters for the production of rice husk and saw dust briquettes using Central Composite Design. The briquettes were produced mechanically with a hydraulic operated briquette machine using cassava starch as a binder. Three numeric factors which were binder ratio, compaction pressure and dwelling time and one categoric factor which was the type of biomass with two levels of saw dust and rice husk were studied. Calorific value of the produced briquette was used as the response of interest. Prior to compaction, the biomasses were carbonized to reduce the volatile matter and to increase their energy content. Quadratic model was generated and validated for the optimization process. Maximal calorific value of 29528.6KJ/Kg was obtained for saw dust briquette at compaction pressure of 85.03Kgf, binder ratio of 18.9% and dwelling time of 40.22mins, while that of rice husk was calorific value of 26387.1KJ/Kg, at compression pressure of 75.02Kgf, binder ratio of 10% and dwelling time of 30mins. It was observed that the produced briquettes comparatively had good properties.

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1. Introduction

The Nigerian energy sector had tremendous change recently. The Nigerian government made it clearly that it want to deregulate and restructure the energy sector with the goal being to completely unbundle the oil and gas sector and to privatize the power sector (Ley et al 2014). The recent increase in the price of petrol and the rise in the cost of diesel are forcing consumers to rethink. Consequent upon this, attention has been shifted from fossil fuel which is a non renewable energy to renewable form of energy. In this way, biomass and waste will play an important role in renewable energy generation. Researchers had found out that most of these biomasses contain energy that is renewable from time to time (Wilaipon 2008; Oladeji and Olafimihan 2008). However, using these biomasses in their present form will not bring a desired result because most of them are loose low density materials (Enweremadu et al. 2004). It was equally observed that the combustion of these materials cannot be effectively controlled when used in loose form (Wilaipan 2007). The best way of converting these materials into renewable energy is by briquetting.

Briquetting is a process of compaction of residues into a product of higher density than the original material (Olorunnisola 2007; Wilaipon 2008). Briquetting represents one of the possible solutions to the local energy shortages in the country. It constitutes a positive solution to the problem of increasing rates of desertification associated with high fuel wood consumption (Oroka and Thelma 2013).

This research work tends to optimize the process conditions for briquetting using Response surface Methodology (RSM). RSM is an important subject in the statistical design of experiments, it is a collection of mathematical and statistical techniques useful for the modeling and analysis of problems in which a response of interest is influenced by several variables and the objective is to optimize the response (Ejikeme et. al. 2014). Central Composite Design (CCD) was used as a type of RSM for the optimization process. The optimization involves categoric factor which was the type of biomass with two levels of saw dust and rice husk.

2. Materials and Methods

All materials used were sourced locally. They include the following:

Sawdust

The sawdust was collected from Abakpa Timber market, Abakpa Nike, Enugu, Enugu state, South Eastern Nigeria.

Risk husk

The rice husk was collected from Adani in Uzo-Uwani LGA of Enugu State, South East Nigeria.

Cassava starch

Cassava Starch which was used as binder was procured from Abakpa Nike market in Enugu, Enugu State, South Eastern Nigeria.

a. Briquette production method

Carbonization of the biomass sample was carried out at a temperature of 400°C using a muffle furnace. After allowing cooling to room temperature, the biomass sample was weighed using a digital weighing balance. The binder was gelled at different weight percentages of the biomass. The biomass-binder mixture was transferred into the mould of the hydraulic press briquetting machine and compacted to form briquette at different compaction pressures. The briquette was removed after specified dwell times. After the ejection of the briquette from the mould cavity, it was allowed to dry until constant weight was achieved.

b. Characterisation of the produced briquettes

Proximate analysis as well as the physical properties of the briquettes produced from rice husk and saw dust was determined. The proximate analysis was done according to the work done by Akouwah et al 2012 and they are; moisture content, ash, volatile matter, fixed carbon, carbon, hydrogen and nitrogen. The physical properties were; relaxed density which was done according to Olugbade and Mohammed 2015, Porosity index done according to Ikelle and Ivons 2014, water resistance capacity and durability index done according to Davies and Davies 2013.

c. Calorific value determination.

The calorific value was measured using bomb calorimeter (model XRY-1A, Shanghai Changji, China). It involved igniting 1g of the sample in oxygen bomb calorimeter under a high pressure of oxygen gas. The heat energy that was released was absorbed by the surrounding water inside the bomb calorimeter. This gave rise to a temperature increase of the surrounding water and this was used to estimate the energy value of the sample. The heat of combustion was calculated as the gross energy.

d. Optimization of process factors for briquette production

The central composite design used for the optimization involved three numeric factors which are compaction pressure, dwelling time and binder ratio and one categoric factor which is the type of biomass. The categoric factor has two levels which are saw dust and rice husk. The three numeric factors gave twenty runs which when multiplied with the two levels of the categoric factor gave total number of forty runs. The response of interest used for the optimization was the calorific value of the briquette. Table 1 shows the factors and levels used for the optimization.

Table 1. Factors and Levels used for the optimization process

			Levels				
	Factors	Units	-α	-1	0	+1	+α
1	Pressure	Kgf	20	40	60	80	100
2	Dwelling Time	Mins	10	20	30	40	50
3	Binder ratio	%	10	15	20	25	30
4	Type of biomass						
A	Rice Husk						
B	Saw dust						

3. Results and Discussions

Table 2 below shows the results of the characterization of the produced briquettes. The total energy that is needed to bring a briquette up to its pyrolytic temperature is dependent on its moisture content which affects the internal temperature within the briquette due to endothermic evaporation (Zaror and Pyle 1982). A lower moisture content of the produced briquettes implied a higher calorific value (Akowuah et al 2012). The amount of volatile matter strongly influences the thermal decomposition and combustion behavior of solid fuels (Wamukonya and Jenkins 1995).

Table 2. Characteristics of the produced briquettes

	Parameters	Units	Rice husk Briquette	Saw dust Briquette
	PROXIMATE ANALYSIS			
1	Moisture	%	2.6	2.0
2	Ash	%	3.8	3.2
3	Volatile Matter	%	22.5	18.8
4	Fixed Carbon	%	71.1	76.0
5	Carbon	%	83.0	85.4
6	Hydrogen	%	4.4	4.3
7	Nitrogen	%	1.7	1.7
	PHYSICAL PROPERTIES			
8	Relaxed density	g/ml	0.4080	0.4077
9	Durability Index	%	32.845	30.6713
10	Porosity Index	-	0.688	0.697
11	Compression density	g/ml	0.7117	0.7727
12	Water Resistance	%	31.2	30.32
13	Water Absorption	%	68.8	69.68

The high volatile content of the biomass briquettes indicated easy ignition of the briquette and proportionate increase in flame length (Deapak and Jnanesh 2005). Low amount of ash content indicates low dust, more efficiency and combustion rate. The ultimate analysis indicates the various chemical constituents such as hydrogen, carbon and nitrogen. The amount of hydrogen content in the biomass briquette is very satisfactory as they contribute immensely to the combustibility of any substance in which they are found (Chaney 2010). The low nitrogen contents is a welcome development as there will be minimal release of nitrogen oxides into the atmosphere and that is an indication that the burning of the briquette will not pollute the environment.

a. Selection of a good predictive model for briquette production process

A good predictive model is the prerequisite for optimization process. Sequential model sum of squares was used to select the best model based on the highest order model that was significant (small p-value) and not aliased, no lack of fit (p-value > 0.1) and reasonable agreement between adjusted R-Squared and predicted R-squared (within 0.2 of each other). Lack of fit which is the measure of risk was included because some points were replicated (centre points) to produce estimate of pure error. Quadratic models were suggested based on the above stated conditions for the two heating methods. The suggested model had significant p-value, non-significant lack of fit value, and good agreement between the adjusted and predicted R-squared (within 0.2 each other).

b. Analysis of variance (ANOVA) for the briquette production process

The suggested models were inspected for adequacy for predicting the response using Analysis of variance (ANOVA). ANOVA tested the suggested model, the linear terms, interaction terms and the quadratic terms included in the model. A term was removed from the model only when it had insignificant p-value (> 0.05) or was retained in model to support model hierarchy. Table 3 shows the analysis of variance for the briquette production process.

The Model F-value of 172.43 implied that the model was significant. There was only a 0.01% chance that a "Model F-Value" this large could occur due to noise. Values of "Prob > F" less than 0.0500 indicated model terms were significant.

In this case single effect of compression pressure (A), dwelling tine (B), binder ratio (C), and type of biomass (D), interaction effece of compression pressure and binder ratio (AC), quadratic effect of compression pressure (A2), quadratic effect of dwelling time (B2), and quadratic effect of binder ration (C2) were significant model terms. Values greater than 0.1000 indicated the model terms were not significant. The "Lack of Fit F-value" of 1.12 implied the Lack of Fit was not significant relative to the pure error. There was a 44.71% chance that a "Lack of Fit F-value" this large could occur due to noise. The "Pred R-Squared" of 0.9628 was in reasonable agreement with the "Adj R-Squared" of 0.9723. Adeq Precision measures the signal to noise ratio. A ratio greater than 4 is desirable. A ratio of 48.918 obtained indicated an adequate signal.

c. Model equations for the briquette production process

Table 3: Analysis of variance for the briquette production process

Source	Sum of squares	Df	Mean Square	F value	P – value, Prob > F
Model	2.901E+8	8	3.626E+007	172.43	<0.0001
A – Pressure	5.847E+7	1	5.847E+007	278.02	<0.0001
B – Dwelling time	9.367E+5	1	9.367E+005	4.45	0.0430
C – Binder weight	7.840E+7	1	7.840E+007	372.77	<0.0001
D – Biomass types	9.796E+7	1	9.796E+007	465.82	<0.0001
AC	1.629E+6	1	1.629E+006	7.74	0.0091
A^2	2.715E+7	1	2.715E+007	129.08	<0.0001
B^2	2.043E+6	1	2.043E+006	9.72	0.0039
C^2	3.628E+7	1	3.628E+007	172.50	<0.0001
Residual	6.520E+6	31	2.103E+005		
Lack of fit	4.570E+6	21	2.176E+005	1.12	0.4471
Pure Error	1.949E+6	10	1.949E+005		
Cor Total	2.966E+8	39			
R-Squared	0.9780				
Adj R-Squared	0.9723				
Pred R-Squared	0.9628				
Adeq Precision	48.918				

The model equations were presented both in actual form and coded form and is the final equation after removing the insignificant factors. Response prediction can only be done with the coded form because the actual form has been scaled to accommodate their various units. The responses generated using the model equation was compared with the experimental values and residuals were generated according to standard run as shown on Table 4. The residuals were analysed with the aid of diagnostic plots which were; normal plots of residuals, residual vs predicted values, residual vs run and predicted vs actual values. Figure 1 show the diagnostic plots for the residuals.

Final Equation in Terms of Coded Factors: Calorific value (KJ/Kg) = +26824.20+1351.73A +171.09B+1565.22C + 1564.97D - 319.04A C - 734.75A2-201.57B2-849.38C2 (1)

Final Equation in Terms of Actual Factors:

RICE HUSK;

Calorific value (KJ/Kg) =-2947.59966+335.86787 Pressure (Kg)+138.05199 Dwelling time (mins)+1523.72648* Binder weight (%)-3.19038 Pressure (Kg) Binder weight (%)-1.83688 Pressure (Kgf)2 - 2.01571 Dwelling time (mins) 2 -33.97534 Binder weight (%)2 (2)

SAW DUST;

Calorific value (KJ/Kg) =+182.33034 +335.86787* Pressure (Kg)+138.05199 Dwelling time (mins)+1523.72648 Binder weight (%)-3.1903 Pressure (Kg) Binder weight (%)-1.83688 Pressure (Kg) 2-2.01571 Dwelling time (mins)2-33.97534 Binderweight (%)2 (3)

Table 4. Residuals generated from the model equation for the briquette production process

Standard order	Actual Value	Predicted Value	Residual
1	19851.8	20066.44	-214.64
2	22652.1	23407.98	-755.88
3	20335.6	20408.63	-73.03
4	2433.4	23750.17	283.23
5	23866.8	23834.95	31.85
6	26390.3	25900.34	489.96
7	24390.3	24177.14	213.66
8	26121.5	26242.53	-121.03
9	19972.8	19616.76	356.04
10	24955.2	25023.68	-68.48
11	24114.1	24110.76	3.34
12	24818.1	24795.13	22.97
13	19604.6	18731.26	873.34
14	24468.8	24992.13	-523.33
15	25441.7	25259.23	182.47
16	25457.8	25259.23	198.57
17	25178.2	25259.23	-81.03
18	25151.4	25259.23	-107.83
19	25430.9	25259.23	171.67
20	24377.4	25259.23	-881.83
21	22499.5	23196.37	-696.87
22	26569.4	26537.91	31.49
23	23045.9	23538.56	-492.66
24	26020.0	26880.10	-860.10
25	27050.2	26964.88	85.32
26	29561.4	29030.27	531.13
27	27644.4	27307.07	337.33
28	29316.5	29372.46	-55.96
29	22636.9	22746.69	-109.79
30	28292.4	28153.61	138.79
31	27327.9	27240.69	87.21
32	28128.1	27925.06	203.04
33	22218.8	21861.19	357.61
34	27731.0	28122.06	-391.06
35	28534.2	28389.16	145.04
36	28820.9	28389.16	431.74
37	28850.7	28389.16	461.54
38	27626.5	28389.16	-762.66
39	28504.4	28389.16	115.24
40	28832.8	28389.16	443.64

d. Diagnosis of model equations using residual plots

Normal Plot of Residuals

Figure 1a shows the graph of normal plot of residuals. The normal probability plot indicates whether the residuals follow a normal distribution, in which case the points will follow a straight line.

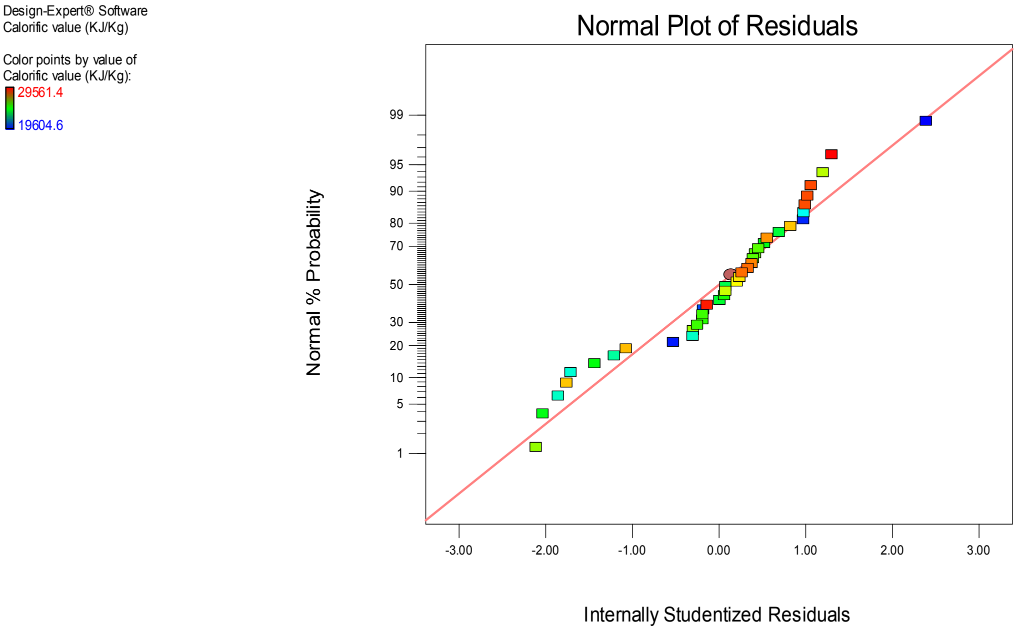

Figure 1a. Normal plot of residuals for briquette production process

Residuals vs. Predicted Plot

Figure 1b shows the graph of residuals vs. predicted response. This is a plot of the residuals versus the ascending predicted response values. It tests the assumption of constant variance. The plot should be a random scatter (constant range of residuals across the graph.)

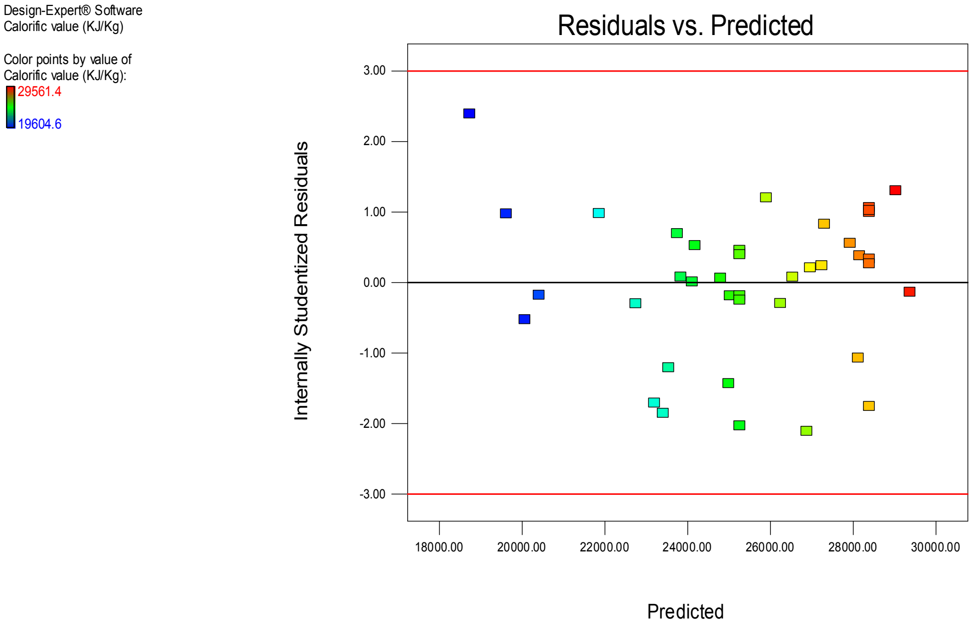

Figure 1b. Residuals versus predicted diagnosis plot of residuàls for briquette production process.

Residuals versus Run

Figure 1c shows the graph of residual vs run. This is a plot of the residuals versus the experimental run order. It allows you to check for lurking variables that may have influenced the response during the experiment. The plot should show a random scatter.

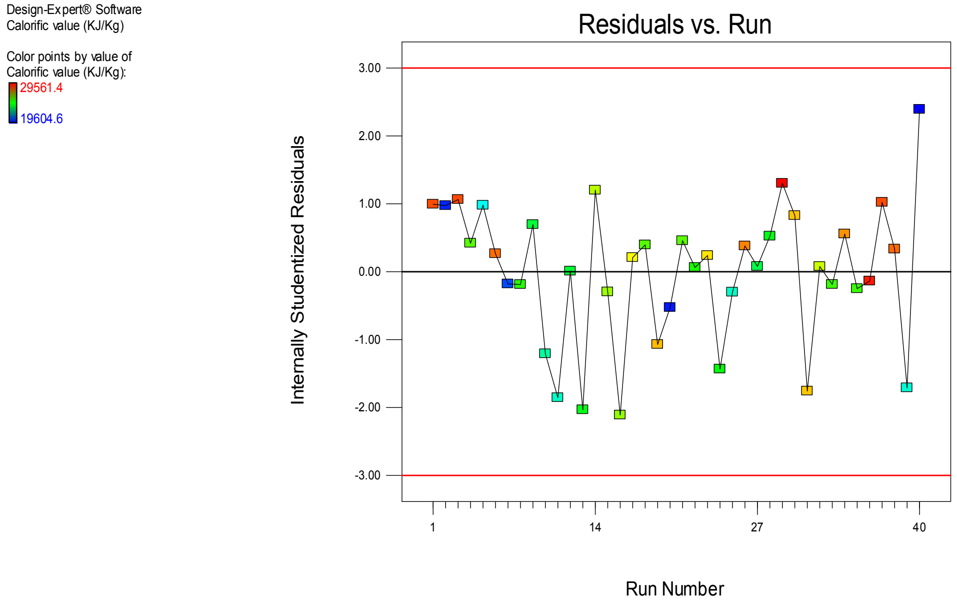

Figure 1c. Residuals versus run diagnosis plot of residuàls for briquette production process

Predicted versus Actual

Figure 1d shows the graph of the actual response values versus the predicted response values. It helps you detect a value, or group of values, that are not easily predicted by the model. The data points should be split evenly by the 45 degree line.

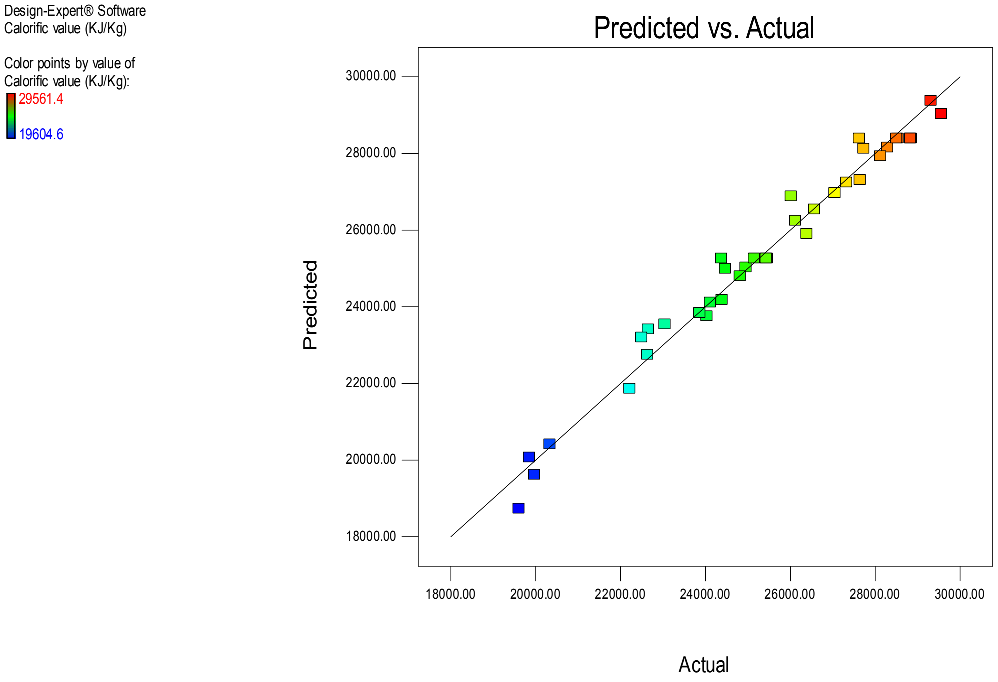

Figure 1d. Predicted versus actual diagnosis plot of residuàls for briquette production process

As can be seen from Figures 1a-d, the graphs followed the normal pattern which showed that the model equation generated can be used to predict the response which is the calorific value of briquette.

e. Model graphs for briquette production process

From ANOVA table (Table 3), the interaction of compression pressure and binder's weight was observed and thus was plotted on Figure 2. From this plot, it was observed that calorific value was increased as the two factor were increased to an extent that further increase on both factors decreased the calorific value. Increase in pressure and binder weight increased the compaction of the briquette which in turn increases the caorific value. Increasing the binder ratio more than the optimum condition resulted in decrease in biomass content and increase in binder content which decreased the calorific value because biomass naturally has higher calorifc value than the binder. Equally, increase in pressure more than the optimum condition resulted to loss of the binder because some of the binder were expelled at higher pressure.

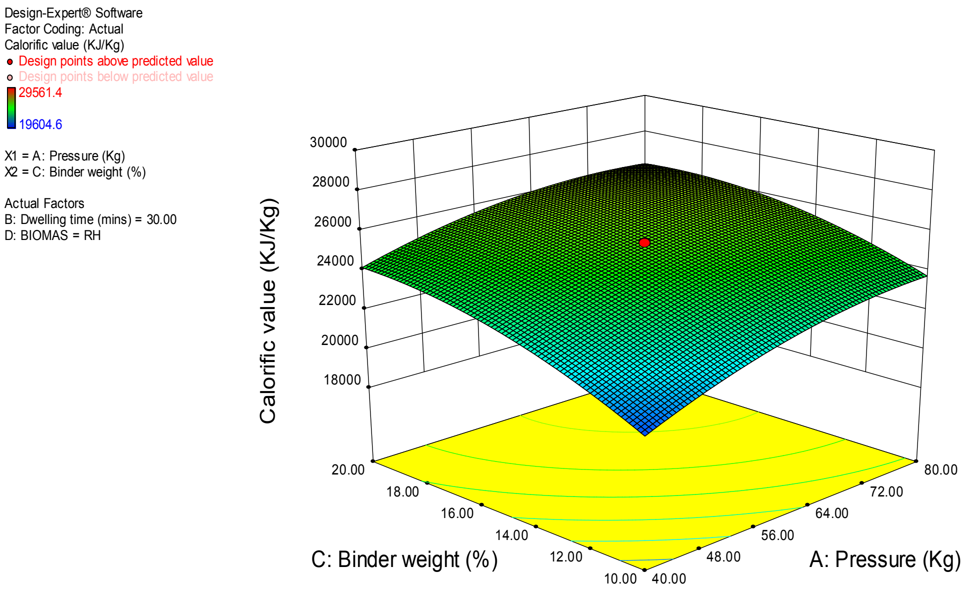

Figure 2. 3D Surface plot for the interaction effect of binder weight with pressure on the calorific values of the briquette.

f. Optimum conditions

Process factors for the briquette production were numerically optimized and validated as shown on table 5.

The optimum conditions were presented based on the categoric factor. The optimum conditions were validated by repeating the experiment at the aid optimum condition and the experimental values were obtained. From the table, it was observed that the errors obtained were less which means that the model equation generated can actually be used for response prediction.

Table 5. Optimum and validated conditions for the briquette production process

Biomass	Dwelling time (mins)	Binder Ratio (%)	Pressure (Kg)	Calorific value (KJ/Kg)		Error (%)
				Predicted values	Experimental Values	
SD	40.22	18.90	85.03	29543.4	29528.6	0.05
RH	30.0	10.0	75.02	26413.5	26387.1	0.10

Conclusion

The following conclusions were drawn from this study;

- That briquetting with mechanical hydraulic press converted rice husk and saw dust to a denser product through compaction and densification.
- That rice husk and saw dust with cassava starch as binder can be processed into a good briquette that can be used for domestic cooking.
- Binder weight, dwelling time and compaction pressure has effect on the calorific value of briquettes.

- Quadratic model generated can be used to predict the calorific value of the briquette.
- Maximal calorific value of 29528.6KJ/Kg can be produced from saw dust using pressure of 85.03Kgf, binder ratio of 18.9% and dwelling time of 40.22mins.
- Maximal calorific value of 26387.1KJ/Kg can be produced from rice husk using pressure of 75.02Kgf, binder ratio of 10% and dwelling time of 30mins.

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