5th International Conference of the International Commission of Agricultural and Biosystems Engineering (CIGR)

Hosted by the Canadian Society for Bioengineering (CSBE/SCGAB)
Virtually from Québec City, Canada – May 11-14, 2021

TITLE

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CSBE21665 – Presented at 5th International Conference of the International Commission of Agricultural and Biosystems Engineering (CIGR)

ABSTRACT Briquettes were produced from mixed composition of three agricultural residues; groundnut shell, almond shell and rice husk. Cassava starch, clay and water were also added. Mixture-Process experimental design of six components and four process factors were used to develop the briquettes. The properties determined were: percentage volatile matter, percentage ash content, percentage fixed carbon and calorific value. Density and drying time were also determined. All processing variables assessed were not significantly different at 5% level of probability, except for percentage ash content. The result shows that briquette produced from composition of 52% groundnut shell, 10% almond shell, 10% rice husk, 20% cassava starch, 5% clay, 3% water, at 650^{o}C carbonising temperature, 250Mpa compacting pressure, 300 sec dwell time and drying temperature of 160^{o}C produced the highest calorific value of 29994.49kcal/kg while briquette produced from 46% groundnut shell, 10% almond shell, 16% rice husk, 20% cassava starch, 5% clay, 3% water, at 300^{o}C carbonising temperature, 250Mpa compacting pressure, 60 seconds dwell time and drying temperature of 160^{o}C produced the lowest calorific value of 23701.47kcal/kg . A burning rate of 0.43kg/hr shows that the fuel is moderately combustible.

Keywords: Almond shell, Cassava starch, Clay, Groundnut shell, Rice husk.

INTRODUCTION Many developing countries produce large volume of agricultural wastes and the inadequate disposal / utilisation of these wastes is becoming a great challenge due to its negative impact on the environment (Maninder *et al.,* 2012). These residues / wastes hold great promise in the area of renewable energy. According to Mckendry (2002), residues which would normally have been classified as wastes are now the bedrock for energy production due to advances in the knowledge of biotechnology and bioengineering. Amoco, (2005) reported that the global rate of energy consumption has doubled in the last three decades of the previous century, thus the need to investigate other sources of fuel/energy apart from fossil fuels. Renewable energy technologies are safe source of energy that have much lower environmental impact than conventional energy technologies. The world has relied so much on fossil fuel and this has had a lot of negative impact on the environment. Biomass is already gaining popularity worldwide as a source of renewable energy as well as better alternative to fossil fuels (Amoco, 2005).

Briquetting is the compaction of agricultural wastes (loose biomass) into compact solid composites of different sizes with the application of pressure, which then makes them easy to use, transport and store (Wilaipon, 2008). Briquetting of agricultural residues takes place with the application of pressure, heat and binding agent on the loose materials to produce the briquettes (Bhattacharya, 1985). According to Olorunnisola (2007), briquetting involves the use of materials that are not dense, compressing them into a solid fuel of a convenient shape that can then be burned like wood or charcoal. Biomass briquetting technology has the potential to reduce greatly, the rate of deforestation in developing countries, because more energy is obtained from less wood.

There are a lot of agricultural residues that can be used for fuel briquettes, these include but not limited to saw dust, wheat straw, groundnut shell, coconut fibre, wood dust (Mandal *et al.,* 2018). According to FAO (1996), some of the best agro-residues for briquetting are: rice husk, groundnut shell and jatropha curcas L. shell.

As noted earlier, lots of agricultural wastes are being generated daily in the Country; converting these residues to briquettes will go a long way in mitigating environmental pollution problems while at the same time creating/generating energy for not only domestic purposes but industrial purposes as well.

2. MATERIALS AND METHODS

2.1 Materials

The briquette fuel was made using the following agricultural residues: rice husk, groundnut shell and almond shell. A briquette press of hydraulic type was used for compacting the fuel into a solid cylindrical mass. Clay was used as filler which also functioned as heat retainer. Cassava starch was used as a binder. Samples of groundnut shells were obtained from a local farmer in Gidan kwano village, Niger state, while rice husk samples were obtained from a local rice processor. Almond shell samples were obtained from Oro village in Kwara State.

2.2 Methods/Procedure

2.2.1 Raw Material Preparation

The samples (rice husks, groundnut shells and almond shells) were sun dried for fourteen days until constant weight of each of the residues were obtained. After drying, the residues were then milled into powder with a hammer mill and sieved using a 600mics sieve size in other to obtain uniform particle size. After sieving, the samples were weighed based on the experimental design (Table 1).

In all, sixty samples containing the different residues were obtained and these were placed in polythene films and labelled accordingly. The mixing ratios were within the range of 20-70% for groundnut shell, 10-40% for almond shell, 2-20% for binder (Cassava Starch), 5% for filler (Clay) and 3% for water. The mixing ratios were arrived at, after extensive literature search and initial tests were carried out.

Only the residues were weighed first; this is because they were later subjected to a process known as carbonization. The starch and clay were only added after compaction. Cassava starch was selected as the binding agent because it is locally available and easy to obtain while clay was selected as the filler because it has high heat retainig capacity, so heat produced during combustion process is not given off easily.

The experimental design (Table 1) shows the ratios at which each of the mixtures was prepared, randomized mixture-process experiment design for six components and four factors was used that gave sixty experimental runs.

Table 1: Experimental design

Run	Groundnut shell A	Almond shell B	Rice husk C	Cassava starch D	Clay E	Water F	Factor 1 Drying Temp.	Factor 2 Carbonising Temp.	Factor 3 Compacting pressure	Factor 4 Dwell time
1	20	40	30	2	5	3	250	650	250	300
2	22	40	10	20	5	3	250	650	250	300
3	20	40	3	2	5	3	160	300	150	300
4	20	40	30	2	5	3	160	300	250	60
5	46	25	10	11	5	3	250	300	150	60
6	26	26	20	20	5	3	250	650	250	60
7	45	24	21	2	5	3	250	300	150	300
8	45	25	10	11	5	3	160	300	150	300
9	52	10	10	20	5	3	250	650	150	60
10	41	39	10	2	5	3	160	300	250	300
11	26	24	30	11	5	3	160	650	150	60
12	70	10	10	2	5	3	250	650	150	300
13	20	40	30	2	5	3	160	300	250	60
14	31	11	30	20	5	3	250	650	150	60
15	40	40	10	2	5	3	250	650	250	300
16	32	10	30	20	5	3	250	300	250	300
17	43	27	20	2	5	3	160	650	150	60
18	60	10	20	2	5	3	206	300	203	180
19	52	10	10	20	5	3	160	650	250	300
20	50	10	30	2	5	3	250	650	150	300
21	52	10	10	40	5	3	250	300	250	300
22	28	24	20	20	5	3	160	650	250	300
23	46	10	16	20	5	3	160	300	250	60
24	50	10	30	2	5	3	160	650	150	60
25	70	10	10	2	5	3	250	650	250	60
26	45	25	10	11	5	3	250	650	250	300
27	22	20	30	20	5	3	160	300	250	60
28	53	10	19	10	5	3	160	650	150	60
29	26	16	30	20	5	3	160	300	150	300
30	25	20	10	12	5	3	160	300	250	60
31	40	40	10	2	5	3	250	300	150	300
32	32	10	30	20	5	3	160	650	250	300
33	20	40	19	13	5	3	160	300	250	60
34	50	10	13	20	5	3	160	300	150	300
35	70	10	10	2	5	3	250	300	150	60
36	28	40	10	14	5	3	250	493	197	173
37	22	40	10	20	5	3	250	300	150	60
38	52	28	10	2	5	3	161	650	250	64
39	40	40	10	2	5	3	250	300	250	60
40	22	40	10	20	5	3	160	300	150	300
41	50	10	30	2	5	3	250	300	150	60
42	20	40	12	20	5	3	160	650	150	60
43	20	40	20	12	5	3	160	300	150	300
44	47	13	30	2	5	3	250	650	250	60
45	70	10	10	2	5	3	250	650	150	300
46	32	10	30	20	5	3	160	650	250	300
47	20	40	30	2	5	3	160	650	150	60
48	29	33	10	20	5	3	160	300	250	60
49	47	13	30	2	5	3	250	650	250	60
50	70	10	10	2	5	3	160	300	250	300
51	20	31	21	20	5	3	160	300	150	60
52	33	26	29	5	5	3	188	545	180	204
53	50	10	30	2	5	3	160	300	250	300
54	20	40	30	2	5	3	250	300	150	60
55	22	40	17	11	5	3	250	300	150	60
56	32	10	30	20	5	3	250	300	250	300
57	40	40	10	2	5	3	160	650	150	60
58	51	10	21	11	5	3	250	650	250	300
59	42	27	21	2	5	3	160	300	250	60
60	70	10	10	10	5	3	160	650	150	60

The residues were carbonised at different temperatures ranging from 300-650 degree Celsius. The carbonisation was done with a locally made furnace and a digital temperature sensor was used for monitoring the temperature. The furnace had two inner chambers, the upper and the lower chamber. This lower chamber housed the fuel used for carbonising while the upper chamber was the carbonising chamber. The fuel used for carbonising was dry bamboo sticks. The sticks were cut into pieces and fed into the fuel unit of the furnace. A pot was placed on a local 3-stone stove which was also loaded with same fuel in other to generate more heat since the process requires high temperature. As soon as this was achieved, the temperature inside the furnace was first measured and if it was determined that it was up to the desired temperature, the first sample was poured into the carbonising chamber and the chamber was fully covered with little or no oxygen allowed to interfere with the process.

The temperature was monitored from time to time so as not to go below the specified temperature and once it was observed that the temperature has gone down a little, additional fuel was fed into the process.
One evidence that indicates a complete carbonization process is that less smoke is produced in the chimney of the carbonising furnace because the process comes with heavy smoke and on completion, the coal was poured into a desiccator and covered so as to allow cooling take place. After this, the sample was placed in the polythene film. This process was carried out for all sixty samples and all sixty samples were carbonised in three days.

Compaction was done using an hydraulic press and the pressure of compaction varied from 150-250Mpa. A 250 Mpa pressure gauge was used to monitor the pressure regime. During compaction, the key element was the binder. The binder from the design varied from 2-20%. This binder was measured and placed in a bowl containing just 3% water. However, the water was boiled to about 60 degrees to help gelatinise the binder. Once this was achieved, the sample (which is also now containing the 5% clay) was poured into the bowl. Continuous stirring was done until the sample became pasty, it was then loaded into the piston press for compaction. The same procedure was repeated for all the samples. The dwell time for compaction also varied for all samples from 60-300 seconds.

The briquettes were ejected after the compaction process had been completed. The briquettes were then placed in an electric Oven to dry at temperatures ranging from 160-250 degrees Celsius. After drying, the percentage ash, percentage fixed carbon, percentage volatile matter, drying time, density of fuel and calorific value were determined. The briquettes were also subjected to a burning rate test using a briquette stove.

2.2.2 Tests on Biomass Fuel

The percentage volatile matter (PVM), percentage ash content (PAC) and percentage fixed carbon (PFC) were determined based on the method described by Emerhi (2011).

The heating value was determined from the equation (HV = 2.326 (147.6C + 1.44V)) reported by Baileys and Blankenhorn (1982).

Bulk densities of ground feed stock briquettes were measured. The bulk density was calculated from the mass of feedstock and briquettes that occupied the container (Density = $\frac{m}{v}$). The burning rate was calculated based on the method described by Olawole and Cyril (2008).

3. RESULTS AND DISCUSSION

3.1 Results

The result from the study is presented in Table 2.

Table 2: Analysis of the Briquette samples

Run	Volatile matter %	Ash content %	Fixed carbon %	Calorific value kcal/kg	Density kg/cubicmetre	Drying time Hrs
1	71.65	17.1	11.25	27861.06	9.34E-08	0.75
2	61.92	22.59	15.49	26057.72	7.91E-08	1
3	70.17	22.27	7.56	26098.5	1.09E-07	2
4	68.81	20.77	10.42	26624.87	1.41E-07	2
5	70.73	17.6	11.67	27697.11	1.03E-07	1.5
6	78.73	13.3	7.97	29106.38	9.21E-08	1.5
7	85.61	10.63	3.76	29965.43	7.02E-08	1
8	83.65	13.11	3.24	29130.41	8.36E-08	2.5
9	75.03	13.32	11.65	29130.5	6.84E-08	1.5
10	82.12	11.66	6.22	29641.04	1.04E-07	2.5
11	81.68	13.09	5.23	29153.78	9.46E-08	2
12	69.34	27.25	3.41	24395.73	9.40E-08	1
13	71.37	15.51	13.12	28409.28	9.73E-08	2.5
14	83.21	10.96	5.88	29889.4	8.74E-08	1.5
15	78.02	16.31	5.67	28078.94	1.17E-07	1
16	74.02	18.58	7.4	27333.11	8.34E-08	0.75
17	63.54	29.22	7.24	23767.96	6.57E-08	2
18	79.72	13.85	6.43	28909.27	8.87E-08	1
19	81.73	10.64	7.63	29994.49	9.66E-08	2.5
20	80.75	11.83	7.42	29594.14	6.90E-08	1.5
21	64.92	29.24	5.84	23749.54	7.14E-08	1.5
22	72.64	21.52	5.84	26335.31	8.94E-08	3
23	60.41	29.49	10.1	23701.47	7.66E-08	3
24	63.64	24.49	11.87	25391.02	6.69E-08	2
25	64.83	22.8	12.37	25961.26	6.17E-08	0.75
26	60.61	27.78	11.61	24286.87	8.98E-08	0.75
27	70.41	28.09	11.51	27534.99	9.26E-08	3
28	70.45	18.83	10.72	27277.17	7.07E-08	2.5
29	69.41	20.62	9.97	26671.34	8.52E-08	3
30	70.34	15.98	13.68	28256.55	7.79E-08	3
31	66.94	22.36	10.7	26094.65	9.18E-08	1
32	79.29	11.11	9.6	29853.56	1.22E-07	2.5
33	73.9	13.35	12.75	29129.66	6.08E-08	2.5
34	65.64	20.61	13.75	26706.34	6.50E-08	2.5
35	69.99	19.33	10.68	27109.36	8.10E-08	0.75
36	70.56	19.16	10.28	27162.95	8.11E-08	1.5
37	66.09	24.04	9.87	25524.99	7.84E-08	1.5
38	72.69	20.79	6.52	26585.51	7.21E-08	2
39	70.95	20.27	8.78	26778.61	7.07E-08	1
40	65.47	21.45	13.08	26419.38	8.11E-08	3
41	67.28	21.59	11.13	26356.16	1.05E-07	1
42	72.94	17.72	9.34	27637.4	8.35E-08	3
43	68.81	17.35	13.84	27799.01	9.14E-08	2.5
44	68.92	20.88	10.2	26586.18	7.57E-08	0.75
45	70.11	18.68	11.21	27331.51	9.23E-08	0.75
46	66.22	23.26	10.52	25791.69	7.34E-08	2.75
47	71.07	22.89	6.04	25878.11	6.00E-08	2
48	65.37	23.91	10.72	25575.65	8.92E-08	3
49	70.39	18.75	10.86	27305.14	9.07E-08	1.75
50	70.05	19.32	10.63	27112.29	7.87E-08	2.5
51	68.38	22.26	9.36	26116.92	9.46E-08	3
52	66.13	23.25	10.62	25795.88	8.90E-08	1.75
53	68.26	23.3	8.44	25760.88	8.82E-08	2.5
54	69.01	22.6	8.39	25994.92	8.11E-08	1.5
55	68.33	22.57	9.1	26010.91	7.82E-08	1
56	64.48	23.06	12.46	25874.93	7.76E-08	1
57	68.39	18.94	12.67	27256.65	8.59E-08	3
58	68.48	20.24	11.28	26809.59	7.57E-08	1.5
59	67.14	22.97	9.89	25883.55	5.66E-08	3
60	71.94	22.87	5.19	25877.69	8.36E-08	2.5

The burning rate, R, was determined to be 0.434kg/hr from the following values: 0.540kg (initial weight of fuel), 0.441kg (final weight of fuel), 12minutes (0.2 hours, time spent) and 14.0 (moisture content of fuel)

$$R(kg/hr) = \frac{100(0.540-0.441)}{(100+14.0)\times 0.2}$$

$$= \frac{100\times 0.099}{114.0\times 0.2} = \frac{9.9}{22.8}$$

R = 0.434kg/hr

Table 3: ANOVA for Linear x Linear model of Percentage Volatile Matter

Source	Sum of Squares	Df	Mean Square	F-value	p-value	
Model	777.55	19	40.92	1.27	0.2566	not significant
(1)Linear Mixture	19.53	3	6.51	0.2019	0.8945	
AE	13.38	1	13.38	0.4148	0.5232	
AF	39.45	1	39.45	1.22	0.2753	
AG	21.34	1	21.34	0.6618	0.4208	
AH	119.86	1	119.86	3.72	0.061	
BE	64.1	1	64.1	1.99	0.1663	
BF	34.48	1	34.48	1.07	0.3074	
BG	51.11	1	51.11	1.58	0.2154	
BH	0.0386	1	0.0386	0.0012	0.9726	
CE	153.63	1	153.63	4.76	0.035	
CF	10.14	1	10.14	0.3145	0.5781	
CG	12.04	1	12.04	0.3732	0.5447	
CH	20.76	1	20.76	0.6436	0.4272	
DE	10.44	1	10.44	0.3236	0.5727	
DF	274.64	1	274.64	8.52	0.0058	
DG	23.12	1	23.12	0.7167	0.4023	
DH	64.17	1	64.17	1.99	0.1661	
Residual	1290.12	40	32.25			
Lack of Fit	1154.55	35	32.99	1.22	0.4575	not significant
Pure Error	135.57	5	27.11			
Cor Total	2067.67	59				
Std. Dev.	5.68		R^2	0.3761		
Mean	70.88		Adjusted R^2	0.0797		
C.V. %	8.01		Predicted R^2	-0.3823		
			Adeq Precision	5.7066		

Where

A = Groundnut shell

B = Almond shell

C = Rice husk

D = Cassava starch

E = Drying temperature

F = Carbonising temperature

G = Compacting pressure

H = Dwell time

3.2 Discussion of Results

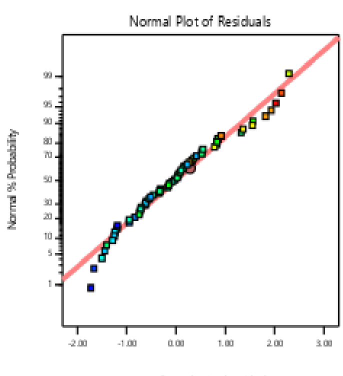
From Table 2, highest calorific value was found to be 29994.49kcal/kg (run 19). The results obtained from the study were subjected to statistical analysis using Design Expert 11.

3.2.1 Percentage Volatile Matter

From Table 3, the Model F-value of 1.27 implies the model is not significant. There is a 25.66% chance that an F-value this large could occur due to noise. P-values less than 0.0500 indicate model terms are significant. In this case A, B, C, D, CE, DF are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. The Lack of Fit F-value of 1.22 implies the Lack of Fit is not significant relative to the pure error. There is a 45.75% chance that a Lack of Fit F-value this large could occur due to noise.

A negative Predicted R^2 implies that the overall mean may be a better predictor of the response than the current model. The value of 5.707 obtained for Adeq Precision indicates an adequate signal.

Figures 13 and 13a shows the normal probability plot and plot of actual values against predicted values respectively. Figure 13b shows that high values for percentage volatile matter is obtained when groundnut shell is not below 20%, almond shell 10% and rice husk 10% respectively.



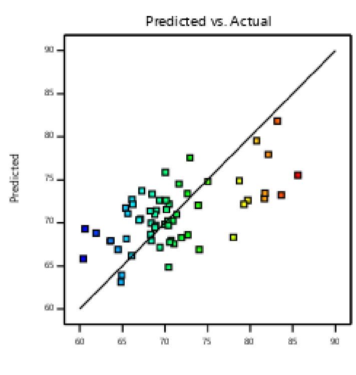


Fig. 13: Normal probability plot of residuals   Fig 13a: Predicted values vs. actual values

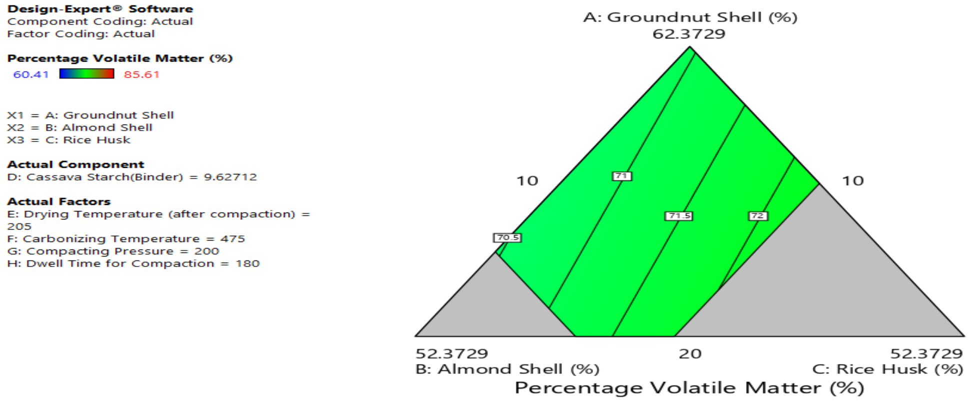


Fig. 13b: Contour Plot

Table 4: Anova Table for Linear x Linear Model of Percentage Ash Content

Source	Sum of Squares	Df	Mean Square	F-value	p-value	
Model	683.25	19	35.96	1.92	0.0413	Significant
[(1)]Linear Mixture	2.25	3	0.7486	0.0399	0.9892	
AE	4.78	1	4.78	0.255	0.6164	
AF	45.84	1	45.84	2.44	0.1258	
AG	10.29	1	10.29	0.5487	0.4632	
AH	14.92	1	14.92	0.7956	0.3778	
BE	63.74	1	63.74	3.4	0.0727	
BF	59.86	1	59.86	3.19	0.0816	
BG	78.3	1	78.3	4.17	0.0477	
BH	1.23	1	1.23	0.0657	0.799	
CE	163.67	1	163.67	8.73	0.0052	
CF	15.35	1	15.35	0.8186	0.371	
CG	1.67	1	1.67	0.0892	0.7667	
CH	41.6	1	41.6	2.22	0.1443	
DE	6.96	1	6.96	0.3711	0.5458	
DF	279.29	1	279.29	14.89	0.0004	
DG	73.99	1	73.99	3.94	0.0539	
DH	6.56	1	6.56	0.3495	0.5577	
Residual	750.24	40	18.76			
Lack of Fit	613.57	35	17.53	0.6413	0.8028	not significant
Pure Error	136.67	5	27.33			
Cor Total	1433.49	59				
Std. Dev.	4.33		**R^2**	0.4766		
Mean	19.79		**Adjusted R^2**	0.228		
C.V. %	21.89		**Predicted R^2**	-0.1288		
			Adeq Precision	7.4132		

3.2.2 Percentage Ash Content

From Table 4, the Model F-value of 1.92 implies the model is significant. There is only a 4.13% chance that an F-value this large could occur due to noise. P-values less than 0.0500 indicate model terms are significant. In this case A, B, C, D, BG, CE, DF are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. The Lack of Fit F-value of 0.64 implies the Lack of Fit is not significant relative to the pure error. There is 80.28% chance that a Lack of Fit F-value this large could occur due to noise. The ratio of 7.413 indicates an adequate signal.

Figures 14 and 14a shows the normal probability plot of residuals and plot of predicted values against actual values respectively. Figure 14b shows that high values for percentage ash content is obtained when groundnut shell is not below 20%, almond shell 10% and rice husk 10% respectively.

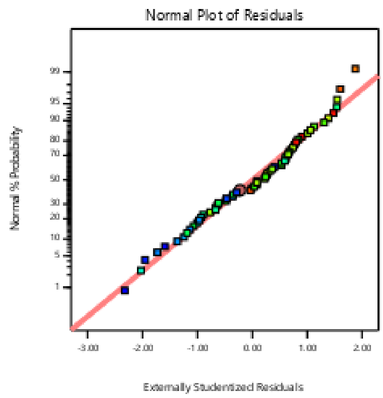


Fig. 14: Normal Probability Plot

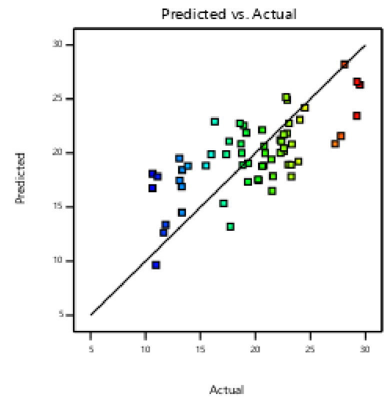


Fig. 14a: Predicted values vs actual values

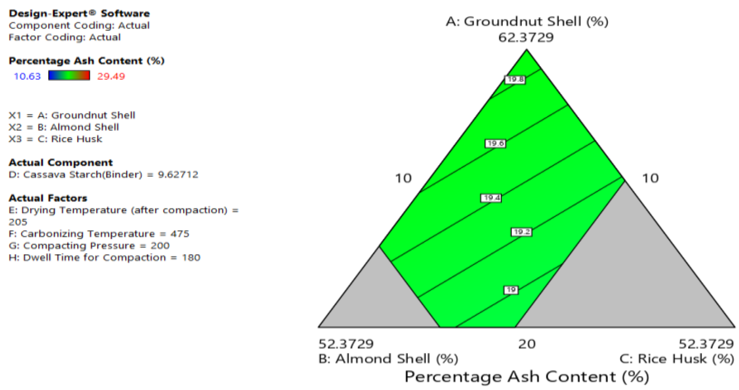


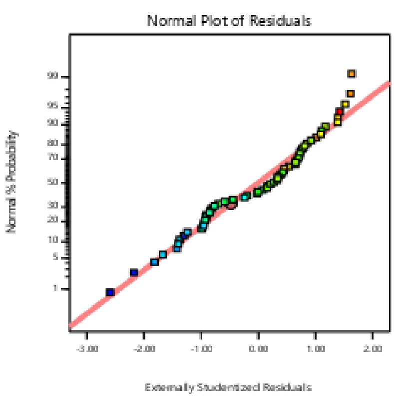
Fig.14b: Contour Plot

Table 5: Anova for Quadratic x Mean Model of Percentage Fixed Carbon						
Source	**Sum of squares**	**df**	**Mean square**	**F-value**	**p-value**	
Model	76.5	9	8.5	1.08	0.3962	not significant
[1]Linear Mixture	20.34	3	6.78	0.8586	0.4687	
AB	27.8	1	27.8	3.52	0.0664	
AC	2.3	1	2.3	0.2919	0.5914	
AD	13.6	1	13.6	1.72	0.1953	
BC	15.06	1	15.06	1.91	0.1733	
BD	7.43	1	7.43	0.9409	0.3367	
CD	1.78	1	1.78	0.2259	0.6366	
Residual	394.75	50	7.89			
Lack of fit	347.24	45	7.72	0.8121	0.6897	not significant
Pure error	47.51	5	9.5			
Cor Total	471.25	59				
Std. Dev.	2.81	**R^2**		0.1623		
Mean	9.5	**Adjusted R^2**		0.0116		
C.V. %	29.57	**Predicted R^2**		-0.2153		
		Adeq Precision		4.3839		

3.2.3 Percentage Fixed Carbon

From Table 5, the Model F-value of 1.08 implies the model is not significant. There is a 39.62% chance that an F-value this large could occur due to noise. P-values less than 0.0500 indicate model terms are significant. In this case A, B are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. The Lack of Fit F-value of 0.81 implies the Lack of Fit is not significant relative to the pure error. There is a 68.97% chance that a Lack of Fit F-value this large could occur due to noise. The ratio of 4.384 indicates an adequate signal.

Figures 15 and 15a shows the normal probability plot of residuals and plot of predicted values against actual values respectively. Figure 15b shows that high values for percentage fixed carbon is obtained when groundnut shell is not below 20%, almond shell 10% and rice husk 10% respectively.



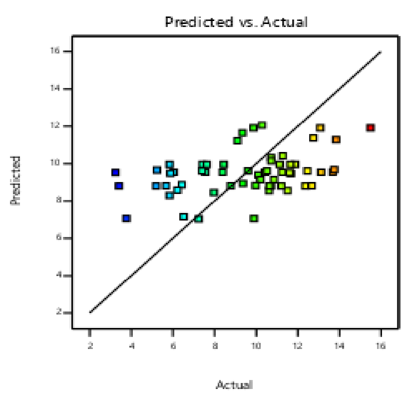


Fig. 15: Normal Probability Plot Fig 15a: Predicted values vs actual values

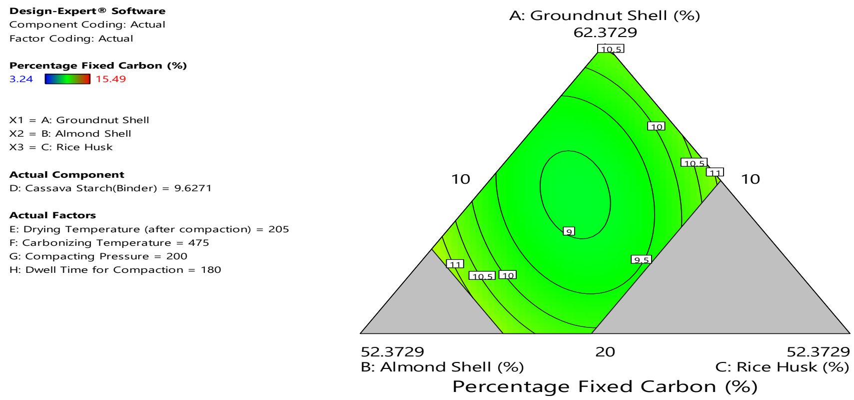


Fig. 15b: Contour Plot

Table 6: ANOVA for Linear x Linear model of Calorific Value

Source	Sum of Squares	Df	Mean Square	F-value	p-value	
Model	6.23E+07	19	3.28E+06	1.45	0.158	not significant
Linear Mixture	1.45E+06	3	4.83E+05	0.2137	0.8863	
AE	2.96E+05	1	2.96E+05	0.1309	0.7194	
AF	3.79E+06	1	3.79E+06	1.67	0.203	
AG	1.71E+06	1	1.71E+06	0.7551	0.3901	
AH	2.27E+06	1	2.27E+06	1.01	0.3221	
BE	5.15E+06	1	5.15E+06	2.28	0.139	
BF	4.67E+06	1	4.67E+06	2.07	0.1584	
BG	7.37E+06	1	7.37E+06	3.26	0.0784	
BH	1.22E+05	1	1.22E+05	0.0542	0.8172	
CE	1.38E+07	1	1.38E+07	6.1	0.0179	
CF	4.31E+05	1	4.31E+05	0.1909	0.6645	
CG	47495.24	1	47495.24	0.021	0.8855	
CH	1.69E+06	1	1.69E+06	0.7491	0.3919	
DE	1.92E+06	1	1.92E+06	0.8506	0.3619	
DF	2.46E+07	1	2.46E+07	10.89	0.002	
DG	5.11E+06	1	5.11E+06	2.26	0.1405	
DH	3.16E+06	1	3.16E+06	1.4	0.244	
Residual	9.04E+07	40	2.26E+06			
Lack of Fit	7.49E+07	35	2.14E+06	0.6917	0.7675	not significant
Pure Error	1.55E+07	5	3.09E+06			
Cor Total	1.53E+08	59				
Std. Dev.	1503.26	R^2	0.4081			
Mean	27002.08	Adjusted R^2	0.127			
C.V. %	5.57	Predicted R^2	-0.3145			
		Adeq Precision	6.2917			

3.2.4 Calorific Value

From Table 6, the Model F-value of 1.45 implies the model is not significant. There is a 15.80% chance that an F-value this large could occur due to noise. P-values less than 0.0500 indicate model terms are significant. In this case A, B, C, D, CE, DF are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. The Lack of Fit F-value of 0.69 implies the Lack of Fit is not significant relative to the pure error. There is a 76.75% chance that a Lack of Fit F-value this large could occur due to noise. The value of 6.292 obtained for Adeq Precision indicates an adequate signal since a ratio greater than 4 is always desirable.

Figures 16 and 16a shows the normal probability plot of residuals and plot of predicted values against actual values respectively. Figure 16b shows that high values for calorific value is obtained when groundnut shell is not below 20%, almond shell 10% and rice husk 10% respectively.

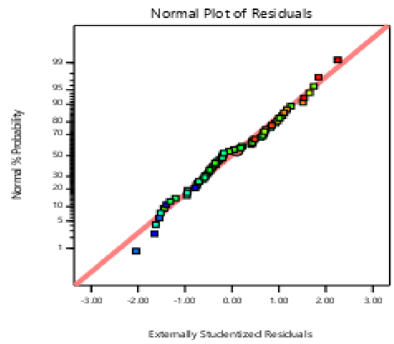


Fig.16: Normal Probability Plot

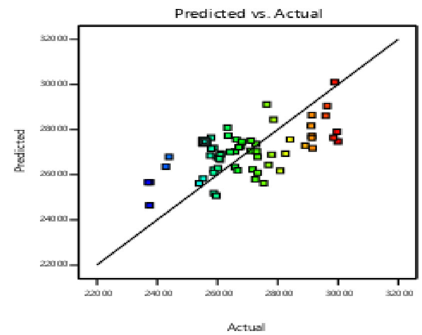


Fig.16a: Predicted values vs actual values

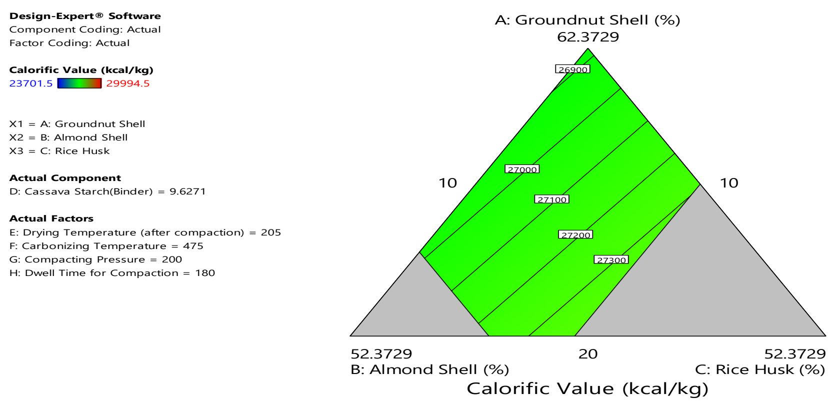


Fig. 16b: Contour Plot

Table 7: ANOVA for Special Cubic x Mean model of Density

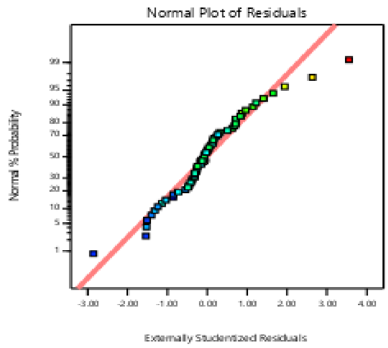
Source		Sum of Squares		Df	Mean Square		F-value	p-value	
Model		3.46E-15		13	2.66E-16		1.15	0.3438	not significant
(1)Linear Mixture		9.30E-16		3	3.10E-16		1.34	0.2722	
AB		8.77E-18		1	8.77E-18		0.038	0.8464	
AC		3.18E-16		1	3.18E-16		1.38	0.2463	
AD		3.51E-16		1	3.51E-16		1.52	0.224	
BC		2.48E-16		1	2.48E-16		1.07	0.3058	
BD		2.94E-16		1	2.94E-16		1.27	0.265	
CD		3.77E-16		1	3.77E-16		1.63	0.2078	
ABC		1.03E-16		1	1.03E-16		0.4457	0.5077	
ABD		3.21E-16		1	3.21E-16		1.39	0.2447	
ACD		1.24E-16		1	1.24E-16		0.536	0.4678	
BCD		2.74E-16		1	2.74E-16		1.19	0.2813	
Residual		1.06E-14		46	2.31E-16				
Lack of Fit		8.35E-15		41	2.04E-16		0.4495	0.93	not significant
Pure Error		2.27E-15		5	4.53E-16				
Cor Total		1.41E-14		59					
Std. Dev.	1.52E-08		R^2			0.2456			
Mean	8.46E-08		Adjusted R^2			0.0323			
C.V. %	17.97		Predicted R^2			-0.2092			
			Adeq Precision			4.0528			

3.2.5 Density

From Table 7, the Model F-value of 1.15 implies the model is not significant. There is a 34.38% chance that an F-value this large could occur due to noise. P-values less than 0.0500 indicate model terms are significant. In this case A is a significant model term. Values greater than 0.1000 indicate the model terms are not significant.

The Lack of Fit F-value of 0.45 implies the Lack of Fit is not significant relative to the pure error. There is a 93.00% chance that a Lack of Fit F-value this large could occur due to noise. The Model F-value of 1.15 implies the model is not significant relative to the noise. There is a 34.38% chance that an F-value this large could occur due to noise. P-values less than 0.0500 indicate model terms are significant. In this case A is a significant model term. Values greater than 0.1000 indicate the model terms are not significant. The value of 4.0528 obtained for Adeq Precision indicates an adequate signal since a ratio greater than 4 is always desirable.

Figures 17 and 17a shows the normal probability plot of residuals and plot of predicted values against actual values respectively. Figure 17b shows that high values for density is obtained when groundnut shell is not below 20%, almond shell 10% and rice husk 10% respectively.



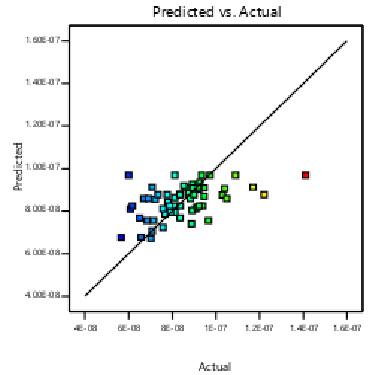


Fig. 17: Normal Probability Plot

Fig. 17a: Predicted values vs actual values

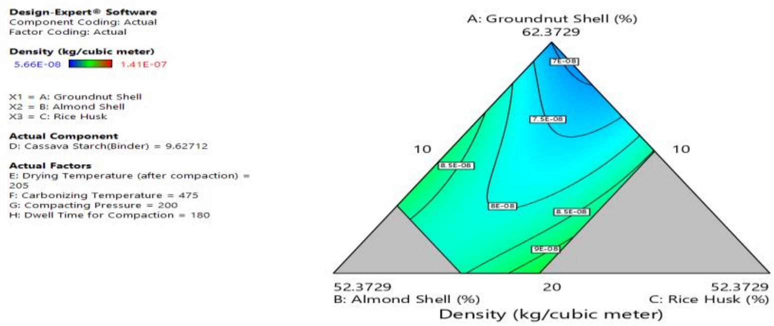


Fig. 17b: Contour Plot

Table 8: ANOVA for Linear x Linear model of Drying Time

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	760.88	19	40.05	1.01	0.4757	not significant
(1)Linear Mixture	169.68	3	56.56	1.42	0.251	
AE	16.72	1	16.72	0.4199	0.5207	
AF	3.27	1	3.27	0.0822	0.7759	
AG	15.04	1	15.04	0.3777	0.5423	
AH	0.0383	1	0.0383	0.001	0.9754	
BE	81.01	1	81.01	2.03	0.1615	
BF	0.2264	1	0.2264	0.0057	0.9403	
BG	2.51	1	2.51	0.063	0.8032	
BH	18.71	1	18.71	0.4698	0.497	
CE	21.24	1	21.24	0.5334	0.4694	
CF	62.24	1	62.24	1.56	0.2185	
CG	62.92	1	62.92	1.58	0.2161	
CH	2.8	1	2.8	0.0702	0.7924	
DE	91.65	1	91.65	2.3	0.1371	
DF	18.5	1	18.5	0.4644	0.4995	
DG	1.21	1	1.21	0.0303	0.8627	
DH	43.52	1	43.52	1.09	0.3021	
Residual	1592.93	40	39.82			
Lack of Fit	359.86	35	10.28	0.0417	1	not significant
Pure Error	1233.06	5	246.61			
Cor Total	2353.81	59				

Std. Dev.	6.31	R^2	0.3233
Mean	3	Adjusted R^2	0.0018
C.V. %	210.06	Predicted R^2	-0.5425
		Adeq Precision	5.3889

3.2.6 Drying Time

From Table 8, the Model F-value of 1.01 implies the model is not significant. There is a 47.57% chance that an F-value this large could occur due to noise. P-values less than 0.0500 indicate model terms are significant. In this case there are no significant model terms. Values greater than 0.1000 indicate the model terms are not significant.

The Lack of Fit F-value of 0.04 implies the Lack of Fit is not significant relative to the pure error. There is a 100.00% chance that a Lack of Fit F-value this large could occur due to noise..

The value of 5.389 obtained for Adeq Precision indicates an adequate signal, since a value greater than 4 is always desirable.

Figures 18 and 18a shows the normal probability plot of residuals and plot of predicted values against actual values respectively. Figure 18b shows that high values fr calorific value is obtained when groundnut shell is not below 20%, almond shell 10% and rice husk 10% respectively.

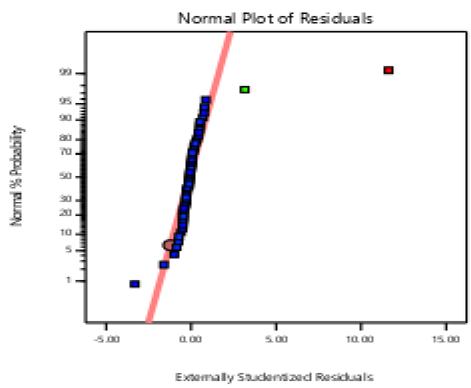


Fig. 18: Normal Probability Plot

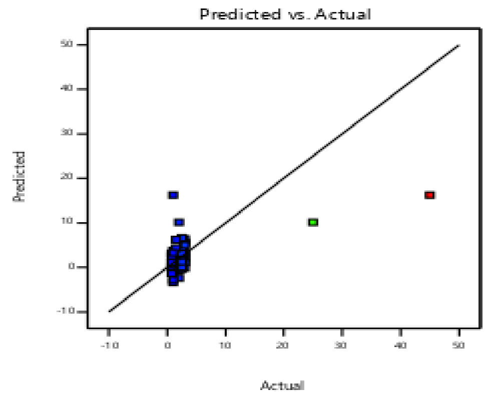


Fig 18a: Predicted values vs actual values

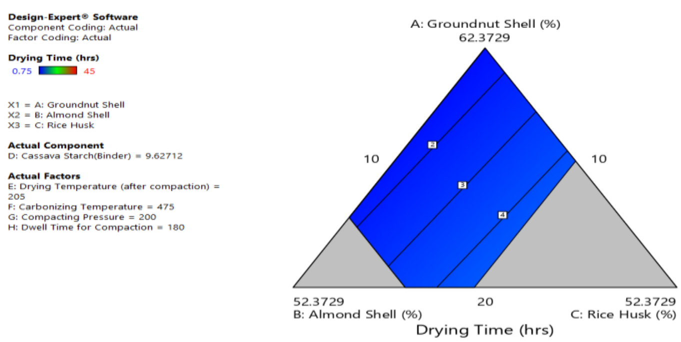


Fig. 18b: Contour Plot

CONCLUSIONS

This study was carried out to produce briquettes from some selected agricultural residues using other additives such as clay, binder and water to achieve the desired level of combustion. All processes involved in briquette production ranging from residue collection, drying, milling, sieving, carbonizing, compacting, ejecting and drying were carefully observed during this study. The result shows that briquette produced from composition of 52% groundnut shell, 10% almond shell, 10% rice husk, 20% cassava starch, 5% clay, 3% water, at 650°C carbonising temperature, 250Mpa compacting pressure, 300 seconds dwell time and a drying temperature of 160°C produced the highest calorific value of 29994.49kcal/kg while briquette produced from 46% groundnut shell, 10% almond shell, 16% rice husk, 20% cassava starch, 5% clay, 3% water, at 300°C carbonising temperature, 250Mpa compacting pressure, 60 seconds dwell time and a drying temperature of 160°C produced the lowest calorific value of 23701.47 kcal/kg. Also, all the processing variables assessed in this study were not significantly different at 5% level of probability, except for percentage ash content. A burning rate of 0.43kg/hr obtained in the study indicates that the fuel is moderately combustible. The briquettes produced based on the formulation releases lesser carbon to the atmosphere is environmentally friendly, and will help to reduce various health hazards associated with the use of fuel wood; deforestation and its attended complications will be reduced as well.

REFERENCES

Amoco, B.P. (2005). *Statistical review of world energy*. [London], [BP Amoco Plc]. http://www.bpamoco.com/downloads/index.asp. Accessed on 25th August, 2018.

Baileys, R. T and Blankenhorn, P.R. (1982). Calorific and porosity development in carbonized wood. Wood Sci.. 15.

Bhattacharya, S.C, Bhatia, R, Islam, M.N, Shah, N. (1985). Densified biomass 8, Thailand, 255-266.

Emerhi E.A (2011): Physical and Combustion Properties of briquettes produced from sawdust of three hardwood species and different organic binders*; Pelajia Research Library,* Vol. 2(6) p239.

FAO, (1996). The briquetting of agricultural wastes for fuel. *Food and Agriculture Organization of the United Nations via Delle Treme di Caracalla,* 00100 Rome, Italy p2-33.

Mandal, S., Kumar, G.V.P., Bhattacharya, T.K., Tanna, H.R and Jena, P.C. (2018). Briquetting of Pine Needles (*Pinus roxburgii*) and their Physical, Handling and Combustion Properties. In: Waste and Biomass Valorization, https://doi.org/10.1007/s12649-0180239-4, pp. 1-10.

Maninder, R, Singh, K and Grover, S (2012). Using Agricultural Residues as a Biomass Briquetting: An Alternative Source of Energy. *IOSR Journal of Electrical and Electronics Engineering (IOSRJEEE),* 1(5):11-15.

McKendry, P. (2002). Energy production from biomass (part 1): Overview of Biomass. Bioresource technology. (83): 37 – 46

Olorunnisola, A. O. (2007). Production of fuel briquettes from waste paper & Coconut husk admixture agricultural engineering international: the CIGR E- journal, vol. Xi

Wilaipon, P (2008). The effect of briquetting pressure on banana-peel Briquette & the banana waste in Northern Thailand, American Journal of applied science. (1): 167 – 171.