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OPTIMIZATION OF THE MIXING RATIO OF ADMIXTURE OF PYROLYZED *Jatropha curcas* Linn. SHELL -*Eucalyptus camaldulensis* Dehnh. WOOD SHAVINGS BRIQUETTES

Fadele, O. K.,Usman M. B., Ariyo, O. C., Emeghara, U. U., Adelani, D. O. and Afolabi, A. O.

Federal College of Forestry Mechanization Afaka Kaduna, Forestry Research Institute of Nigeria.

* **fadeleseyi@yahoo.com, +2348064487957**

ABSTRACT

Agricultural wastes represent huge quantity of renewable sources of energy for domestic and industrial utilization. This study focused on optimization of mixing ratio of admixture of pyrolyzed *Jatropha curcas* seed shell and *Eucalyptus camaldulensis* wood shavings with exudates from *Acacia senegal* as the binder. Response Surface Method was applied in the optimization of the mixing proportions. Bio-char of *Jatropha curcas* seed shell-cum-*Eucalyptus camaldulensis* wood shavings and *Acacia senegal* exudates were considered as the independent factors while the response variable were calorific value and hardness of the briquette. The experimental design was 5 by 5 factorial experimental design. This consists five mixing ratio with mass of 1200g of pyrolyzed *Jatropha curcas* shell to *Eucalyptus camaldulensis* wood shaving proportions of. 0/100, 25/75, 50/50, 75/25 and 100/0 % with 50, 60, 70, 80 and 90 g of *Acacia senegal* exudates as the binder respectively. The calorific value and hardness of the briquette produced from the mixing proportions were determined using a bomb calorimeter and Universal Testing Machine. The optimum mixing ratio and mass of binder were found to be 25/75% and 64.02g which are the recommended mixing ratio and binder quantity. The corresponding response for calorific value and hardness were 19.37 MJ/kg and 3.83 kN respectively. The study further showed that the hardness of the briquette followed an increasing trend with the binder while it decreased with increase in proportion of *Jatropha curcas* seed shell in the mixture. However, the calorific value was found to increase with proportion of *Jatropha curcas* shell in the mixture while it decreased with the binder. The briquette was found to have good handling qualities and also suitable as solid bio-fuel both for domestic and industrial uses.

Keywords: Briquette, mixing ratio, jatropha shell, *Eucalyptus camaldulensis* and *Acacia Senegal*

Introduction

Briquettes represent a viable and sustainable source of renewable energy for industrial and family level use. It is a compressed form of solid fuel produced from biomass (Zheng *et al*., 2010).In Nigeria biomass accounts for 51% of total energy consumption while other sources such as natural gas, hydroelectricity and petroleum products constitute 5.2%, 3.1%, 41.3% of energy consumption (Akinbami, 2001, Olorunnisola, 2007). It is obvious from the foregoing that biomass remains an indispensable source of renewable energy in this part of the world. It is estimated that about 2.7 billion people worldwide, who cannot afford modern fuels depends on biomass for domestic use (UNDP/WHO 2009, Grimsby and Borgenvik, 2013).

Dependency on biomass has resulted to depletion of trees in some of the forest reserves when trees are being felled for fire wood. The demand for biomass fuel is projected to increase to213.4 x10^3 metric tonnes, with decrease in supply to about 28.4 x10^3 metric tonnes by the year 2030 (Adegbulugbe, 1994).Green house gas emission as of one the adverse impact of indiscriminate felling of trees is here with us today. Studies on the use of rejected or undesirable forest and agricultural wastes such as straws, leaves, wood shavings, pods, shells and so on inbriquette production has been conducted and found to be a veritable means in reducing emission of greenhouse gases (Shiferaw *et al.,* 2017, Rajaseenivasan *et al.,* 2016, Olorunnisola, 2007). Forest and agricultural waste could be pyrolyzed andconverted into briquettes. This area of research has been carried out in the past with positive outcome (Prasityousil and Muenjina, 2013).

In production of briquette, parameters such as compression pressure, pyrolysis temperature,moisture content, particles sizes of feedstock, mixing ratio and the type of binder determines the effectiveness and suitability of the briquette for fuel (Maschio *et al*., 1992).Gonzalez *et al.* (2004) studied the optimization of mixing ratio for four different categories of pellets. The optimum mixing ratio was established to be 75:25 using tomato and forest residues,with thermal efficiency of 92.4% when applied in a boiler.Previous studies have shown that optimisation of the mixing ratio of the feed stocks in briquette production is important for quality and efficient solid fuel. In this study, the optimization of the mixing ratio ofconstituting components (binder, *Jatropha curcas* seed shell and *Eucalyptus camaldulensis*) of a briquette was carried in a bid to improve their qualities using lesser quantity of binder.

Materials and Methods

Sample preparation

In the production of the briquettes some undesirable forest and agricultural waste such as *Eucalyptus camaldulensis* wood shavings and *Jatropha curcas* seed shell recovered from its shelling process were collected from Federal College of Forestry Mechanization and Trial Afforestation Research Station Kaduna, Nigeria.The *Eucalyptus camaldulensis* wood shavings and *Jatropha curcas* seed shell were pyrolyzed separately in an improvised kiln. The bio-chars recovered from the kiln were screened using a sieve to obtain finer bio-char particles. The bio-chars recovered were cooled and kept in polythene sacks at room temperature (28±2 ^{o}C).Exudates from *Acacia senegal* was milled and applied as an organic binder for the production of the briquette. This type of binder is more preferable because it is environment friendly.

Optimization of mixing proportion

The optimization of the mixing ratio was carried out using experimental design in Table 1.The experimental design comprises of five factors, five levels i.e., 5×5 Central Composite Rotatable Design (CCRD) having two independent factors such as *Jatropha curcas* shell-cum-*Eucalyptus camaldulensis* wood shavings proportions of 0/100, 25/75, 50/50, 75/25 and 100/0 % with the binder being 50, 60, 70, 80 and 90g.The plan of experimental design comprises of 4 factorial points, 4 axial points and 5 replications at the centre point. In the optimization process, 13 runs were generated in all as shown in Table 2. Response Surface Method (RSM) was adopted for the optimization process. The plan of experiment shown in Table 2 was generated using a statistical package such as Design-Expert 10 by applying Central Composite Rotatable Design of Response Surface Method. The response variables were hardness (a measure of force of resistance to rupture in kN) and calorific value (depicts useful energy in a material per unit mass in kJ/kg) of the briquettes produced while the independent variables were *Jatropha curcas* shell-cum-*Eucalyptus camaldulensis* wood shavings proportions and mass of binder. The mixing proportions in Table 2 were applied in briquette production while the response in terms of hardness and caloric were measured in triplicate after each production. The data obtained during the experiment were analyzed using two factor interaction and quadratic models. The analysis of variance was also carried out for *Jatropha curcas* shell-cum-*Eucalyptus camaldulensis* wood shavings proportions and mass of binder. The CCRD adopted comprises of three major design points which include axial, central and factorial points. Full CCRD was adopted for the experimental design (Montgomery and Runger, 2002; Fadele and Aremu, 2018). The most suitable model was selected on the basis of the significance of additional terms where the model is not aliased; as well as the coefficient of determination. The generalized model relating the dependent variable to the independent variable could be obtained from Equation 1.

$$Y = \beta_0 + \sum_{i=1}^{k} \beta_i X_i + \sum_{i<} \sum_{j=3}^{k} \beta_{ij} X_i X_j X_k + \sum_{i=1} \sum_{j=1}^{k} \delta_{ij} X_i X_j X_k + \varepsilon \quad 1$$

Where: Y is the individual dependent parameter (hardness and calorific value), β_o is the model intercept, $\sum_{i=1}^{k} \beta_i X_i$ characterises the main linear effects of individual independent parameters (jatropha-cum-Eucalyptus mixing ratio and mass of binder), $\sum_{i<} \sum_{j=2}^{k} \beta_{ij} X_i X_j$ determines the relationship between variables, $\sum_{i=1} \sum_{j=1}^{k} \delta_{ij} X_i X_j$ shows the main quadratic effects of the variables, **ε** is random error of experimentation, X_{ijk} shows the matrix of the uncoded process variables. The total number of experimental runs was evaluated in Equation 2 as follow:

$$N = (2^k) + 2k + c \quad 2$$

Where
N is the number of runs
k is the number of independent parameters
c is the centre point.

Table 1. Experimental Levels for Jatropha-cum-Eucalyptus Camaldulensis and Binder Mixing

Factors	**Levels**				
	1	2	3	4	5
Mass of Binder (g)	50	60	70	80	90
Jatropha: Eucalyptus	0:100	25:75	50:50	75:25	100:0

Table 2.Plans of Experimental Runs for the Mixing Ratio

S/No	Jatropha Shell-cum-*Eucalyptus camaldulenis* Wood Shaving (%)	Mass of Binder (g)	Responses	
			Calorific Value (MJ/kg)	Hardness (N)
1	50/50	70	18.95	4.2
2	50/50	70	19.56	3.8
3	75/25	60	15.37	5.3
4	75/25	80	17.23	4.6
5	50/50	70	15.66	3.6
6	50/50	90	16.75	7.5
7	25/75	60	14.05	3.5
8	50/50	70	27.33	3.1
9	50/50	70	21.49	4.7
10	0/100	70	14.64	7

11	100/0	70	15.09	4.6
12	25/75	80	9.66	6
13	50/50	50	31.15	2.6

Determination of calorific value of the briquette

The calorific value of the briquette was determined using a bomb calorimeter (ZDHW-2000) in Leather Research Institute Zaria, Kaduna Nigeria. Thirteen samples of briquettes produced from mixing proportions in Table 1 were tested. Figure 1 shows the diagram of the bomb calorimeter used for the test.

Figure 1.Test for the calorific value of the briquette using a bomb calorimeter

Determination of hardness of the briquette

The hardness of the briquette was determined in accordance with American Society for Testing and Materials standards (ASTM, 2008) using a Universal Testing Machine (Techquipment SN1000) as shown in Figure 2.Thirteen samples of the briquettes were tested and values for hardness and deformation were logged and plotted into a curve on the system as shown in Figure 3. The hardness of the briquette was also optimized.

Figure 2.Test for the compressive strength of the briquette using a Universal Testing Machine

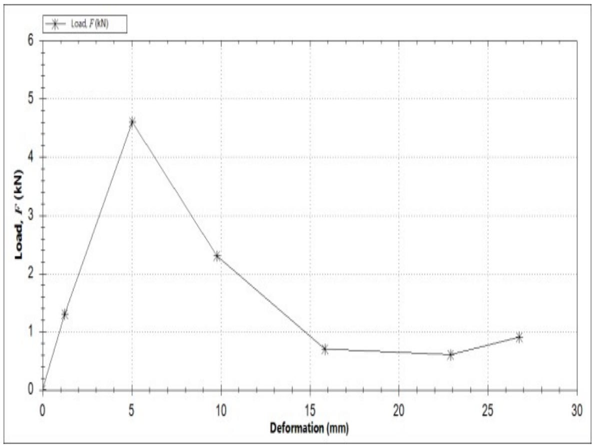

Figure 3. Force deformation curve of the briquette

Results and Discussion

Effect of mixing proportion on the calorific value of *Jatropha curcas*-cum-*Eucalyptus camaldulensis* briquette

The calorific property of the briquette was found to be insignificantly influenced by variation inthe mixing proportion of the bio-char of *Jatropha curcas* shell and *Eucalyptus camaldulensis* wood shavings with the mass of binder as shown in Table 3. This is an indication that variation in all the mixing constituents of the briquette does not have any effect on the calorific value of the briquette which could be as a result of application of constant compressing pressure for all the briquettes. The maximum value obtained was found to be 31.15MJ/kg which is agreement with that of charcoal and biochar from *Jatropha curcas* fruit pods (Openshaw, 2000; Mallika*et al.*, 2015).

However, the minimum value was found to be 9.66 MJ/kg while the average value was 18.23 MJ/kg. The optimum calorific value was 19.37 MJ/kg with desirability of 0.55. The calorific value was found to increase and then decrease with proportion of *Jatropha curcas* shell in the mixture which could be due to the bulk density of jatropha shell which contributed to the energy density of briquette when its proportion increases as shown Figure 4. This is in support of findings by Grimsby and Borgenvik (2013); while it decreases and then increases with the proportion of *Eucalyptus camaldulensis* wood shaving in the mixture as shown in Figure 4. The calorific value alsodecreased with increase in the mass of the binder as shown in Figures 4.Equation 3 shows the mathematical relationship that exist between calorific value and the mixing proportion of *Jatropha curcas* shell-cum-*Eucalyptus curcas* wood shavings with the mass of binder.

$$C = 87.4 - 0.159A - 1.604B + 0.00625AB - 0.00245A^2$$

($R^2 = 0.48$) 3

Where C is the calorific value

A is the proportion of bio-char of jatropha shell to eucalyptus wood shaving

B is the mass of binder

The Model F-value of 1.27 indicatesthat the model is not significant relative to error. There is a37.14 % chance that a F-value this large could occur due to noise.The lack of fit F-value of 2.37 implies that the lack of fit is not significant relative to the pure error. There is a 21.13% chance that a lack of fit F-value this large could occur due to noise. Significance of fit observed data to the model is good since it shows that the observed data follow the curve indicated by the model.The coefficient of determination (R^2) obtained was found to be 0.48. This shows the variation in the constituting components of the briquette to accounts for 48% of the total responses in the calorific value of the bio-char jatropha shell-cum-*Eucalyptus camaldulensis* wood shaving briquette.

Table 3. Analysis of Variance for Relationship between Calorific and Briquette Constituents

SV	SS	Df	MS	F-Value	p-value
Model	187.79	5	37.56	1.27	0.3714^{ns}
A	7.99	1	7.99	0.27	0.6189^{ns}
B	81.80	1	81.80	2.77	0.1398^{ns}
AB	9.77	1	9.77	0.33	0.5831^{ns}
A^2	54.02	1	54.02	1.83	0.2181^{ns}
B^2	12.41	1	12.41	0.42	0.5373^{ns}
Residual	206.50	7	29.50		
Lack of Fit	132.21	3	44.07	2.37	0.2113^{ns}
Pure Error	74.29	4	18.57		
Cor Total	394.29	12			

SV-Source of Variable; SS-Sum of Squares; Df- Degree of freedom; MS-Mean Square; ns-not significant; A-Jatropha curcas-cum-Eucalyptus camaldulensis; B-Binder

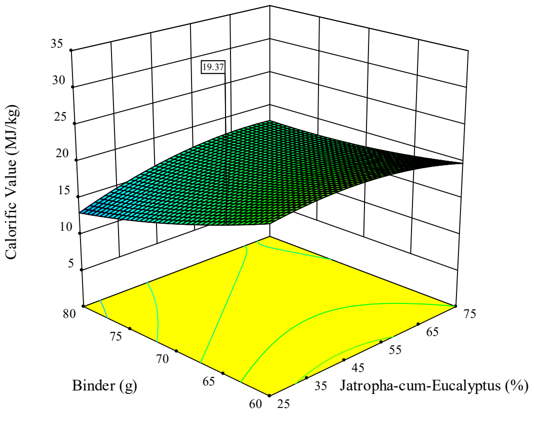

Figure 4. Calorific value against binder and *Jatropha curcas*-cum-*Eucalyptus camaldulensis* bio-char

Effects of mixing proportion on the hardness of the briquette

The hardness of the briquette was found to be significantly affected by the mixing ratio as shown in Table 4. This shows that variation in one or more of the mixing constituents of the briquette have an effect on the hardness of the briquette. The maximum value obtained was found to be 7.5 kN which is acceptable for stability of briquette during handling, transit or utilization. However, the minimum value was found to be 2.6 kN while the average value was 4.65 kN. The optimum value obtained for the hardness was 3.83kN.All these values are within standard values recommended for briquettes production (ASTM, 2008). The hardness was found to decrease with *Jatrophacurcas*-cum-*Eucalyptus camaldulensis*wood shaving proportion while it increases with the binder as shown in Figure5.Similarly, Olugbade*et al.* (2019) reported the improvement of strength through increase in binder proportion. The hardness value was found to decrease with the proportion of bio-char of *Jatrophacuras* shell in the mixture while it increases with that of *Eucalyptus camaldulensis* wood shavings. However, thehardness of the briquetteincreased with increase in the mass of the binder as shown in Figures 5. Equation 3 shows the mathematical relationship that exists between the hardness and jatropha-cum-Eucalyptus wood shavings proportion with the mass of binder.

$$H = 3.134 + 0.132A - 0.158B - 0.0032AB + 0.00077A^2$$

($R^2 = 0.83$) 3

Where H is the calorific value
A is the proportion of bio-char of jatropha shell to eucalyptus wood shaving
B is the mass of binder

The Model F-value of 6.67 shows the model is significant as shown in Table 4. There is only a 1.36% chance that an F-value this large could occur due to noise. The lack of fit F-value of 2.74 implies that the lack of fit is not significant relative to the pure error. There is a 17.75% chance that a lack of fit F-value this large could occur due to noise. Non-significant lack of fit is good since it shows that the observed data fit to the model. The coefficient of determination (R^2) obtained was found to be 0.83. This shows that the variation in the constituting components of the briquette to accounts for 83% of the total responses in the hardness of the bio-char jatropha shell-cum-*Eucalyptus camaldulensis* wood shaving briquette.

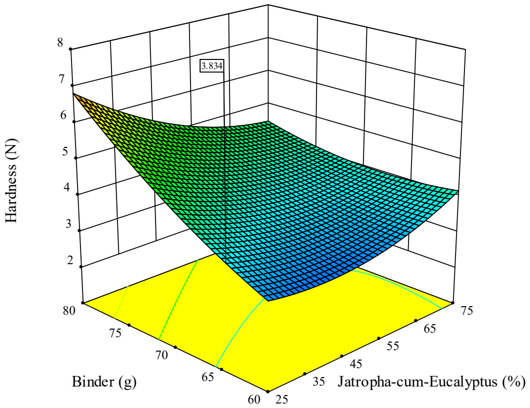

Figure 5. Hardness against binder and jatropha-cum-eulayptus bio-char

Table 4. Analysis of Variance for Relationship between Hardness and Briquette Constituents

SV	SS	df	MS	F-value	p-value
Model	21.37	5	4.27	6.67	0.0136
A-Jatropha	1.61	1	1.61	2.52	0.1565
B-Binder	11.21	1	11.21	17.51	0.0041
AB	2.56	1	2.56	4.00	0.0857
A^2	5.35	1	5.35	8.36	0.0233
B^2	2.01	1	2.01	3.13	0.1201
Residual	4.48	7	0.64		
Lack of Fit	3.02	3	1.01	2.74	0.1775
Pure Error	1.47	4	0.37		
Cor Total	25.85	12			

SV-Source of Variable; SS-Sum of Squares; Df- Degree of freedom; MS-Mean Square; ns-not significant; A-Jatropha curcas-cum-Eucalyptus camaldulensis; B-Binder

Conclusion

The effects of mixing ratios on some engineering properties of pyrolyzed *Jatropha curcas* shell-cum-*Eucalyptus camadulensis* shaving briquette was established. The optimum mixing ratio of the pyrolyzed *Jatropha curcas* shell-cum-*Eucalyptus camadulensis* wood shaving briquette with the binder was found in this study. The optimum value for response variables such as calorific value and hardness were discovered to be similar to existing briquette from other materials. The hardness of the briquette followed an increasing trend with the binder while it decreased with increase in mixing proportion. However, the calorific value was found to increase with jatropha-cum-wood shaving mixing ratio while it decreased with the binder. The briquette was found to be stable and suitable as solid bio-fuel both for both domestic and industrial uses.

References

Adegbulugbe A.O. (1994). Energy-environment issues in Nigeria. *International Journal of Global Energy Issues* 6(12):7-18.

Akinbami J.F.K. (2001). Renewable Energy Resources and Technologies in Nigeria: Present Situation, Future Prospects and Policy Framework. *Mitigation and Adaptation Strategies for Global Change* 6:155-181.

American Society for Testing and Materials-ASTM D2166-85 (2008). Standard Test Method of Compressive Strength of Wood, West Conshohocken.

Fadele, O. K. and Aremu, A. K. (2018). Optimisation of Shelling Efficiency of a *Moringa oleifera* Seed Shelling Machine Based on Seed Sizes. Industrial Crops and Products, 112: 775 – 782.

Gonzalez, J. F., Gonzalez-Garcia, C. M., Ramiro, A., Gonzalez, J., Sabio, E., Ganana, J. and Rodrgueza, M.A. (2004). Combustion Optimisation of Biomass Residue Pellets for Domestic Heating with a Mural Boiler. Biomass and Bioenergy,27:145–154.

Grimsby, L. K. and Borgenvik, E. J. L. (2013). FuelingSawdust Stoves with Jatropha Fruit Coats. Sustainable Energy Technologies and Assessments, 2: 12–18.

Mallika, T., Thanchanok, P., Kasidet, P., Pisit, M., Prasong, W. (2015). Effect of Applied Pressure and binder proportion on the fuel properties of holey bio-briquettes. International Conference on Alternative Energy in Developing Countries and Emerging Economies. Energy Procedia, 79:890 – 895.

Maschio, G., Koufopanos, C. and Lucchesi, A. (1992). Pyrolysis, a Promising Route for Biomass Utilization. *Bioresource Technology,* Vol. 42:219-231.

Montgomery, D.C. and Runger, G.C. (2003). Applied Statistics and Probabilityfor Engineers. 3rd Edition. John Wiley and Sons, Inc. Pp: 14.11.

Olorunnisola, A. (2007). Production of Fuel Briquettes from Waste Paper and Coconut Husk Admixtures. *Agricultural Engineering International*: the CIGR Ejournal. Manuscript EE 06 006.Vol. IX.

Olugbade, T., Ojo, O. and Mohammed, T. (2019). Influence of Binders on Combustion Properties of Biomass Briquettes: A Recent Review. *Bio-Energy Research.* 12:241–259.

Openshaw, K. (2000). A review of *Jatropha curcas*: an oil plant of unfulfilled promise.*Biomass and Bioenergy*, 19:1 – 15.

Prasityousil, J. and Muenjina, A. (2013). Properties of solid fuel briquettes produced from rejected material of municipal waste composting. The 3rd International Conference on Sustainable Future for Human Security, SUSTAIN 2012. Procedia Environmental Sciences, 17:603 – 610.

Rajaseenivasan, T., Srinivasan, V., Syed Mohamed Qadir, G. and Srithar, K. (2016). An investigation on the performance of sawdust briquette blending with neem powder. *Alexandria Engineering Journal*, 55:2833–2838.

Shiferawa, Y., Tedlaa, A., Melesea, C., Mengistua, A., Debaya, B., Selamawia, Y., Merenea, E. and Awoia, N.(2017). Preparation and evaluation of clean briquettes from disposed wood wastes. Energy Sources, Part A: Recovery, Utilization and Environmental Effects, 39(20): 2015–2024.

Zheng, Y. H., Li, Z. F., Feng, S. F., Lucas, M., Wu, G. L., Li, Y. Li, C. H., and Jiang, G. M. (2010). Biomass energy utilization in rural areas may contribute to alleviating energy crisis and global warming: A case study in a typical agro-village of Shandong, China. *Renewable and Sustainable Energy Reviews*, 14:3132–3139.