A Comparative Study of Predictive Models for Densification Parameters of Briquettes Produced From Two Species of Corncob

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ABSTRACT

Corncob is a renewable energy resource, which its great potential for renewable energy generation has not been fully utilized.

Corncobs from white and yellow maize were selected, sun-dried and their moisture contents were determined using ASAE standard. The residues were subjected to size reduction process and three particle sizes 4.70, 2.40 and 0.60 mm were selected. Starch mutillage (binder) was added to the residues at three levels of percentage binder ratios 20, 25, and 30 % by weight of the residue. A briquetting machine was used to form briquettes at three levels of pressures of 2.40, 4.40 and 6.60 MPa with observation of a dwell time of 120 seconds. The bulk density of the unprocessed materials and relaxed briquettes were determined using ASAE standard. The initial, maximum and the relaxed densities of the briquettes were determined using the mould dimension, the relaxed briquette's dimension and ASAE standard method of determining densities. Also determined were the compaction, density and relaxation ratios of the formed briquettes. Percentage axial and lateral expansions were also determined. The experimental data were subjected to regression analysis. A statistical package SPSS version 11.0 was used.

The regression coefficients for the maximum density, relaxed density, compaction ratio, density ratio, relaxation ratio, axial expansion and lateral expansions for briquettes from white maize are 0.72, 0.81, 0.85, 0.84, 0.77, 0.86 and 0.81 respectively, while the corresponding values for briquettes from yellow maize are 0.97, 0.77, 0.98, 0.92, 0.96, 0.82 and 0.84.

The study concluded that there is no significant difference between experimental and predicted results. Hence, all the developed models are reliable.

Keywords: Briquettes, Corncob, Densification, Predictive model, Regression analysis,

I. Introduction

Corncob is a renewable energy resource that has a considerable potential to meet the energy demand in rural areas in Nigeria, especially for domestic and small scale cottage applications.

Corncob residues are abundantly available in Nigeria. This is because Nigeria was the second producer of maize in Africa in the year 2006 with 7.5 million tons [1]. In Nigeria alone, twenty eight different food items can be prepared from maize [2]. South Africa has the highest production of 11.04 million tons [3]. The bulk density of raw corncob is around 50 kg/m^3, whereas the highest bulk density of unprocessed wood is around 250 kg/m^3 [4,5]. Therefore, these bulky residues can be densified into briquettes. Briquetting is a method of increasing the bulk density of biomass by mechanical pressure [6]. Briquettes have low moisture content (about 8% wet basis) for safe storage and high bulk density (more than 600 kg/m^3) for efficient transport and storage. The process of forming biomass into briquettes depends upon the physical properties of ground particles and process variables during briquetting. The compaction process is a complex interaction between particles, their constituents and forces.

Mani et al. 2004 [7] evaluated the compaction mechanism of straws, stover and switch grass using different compaction models.

In order to optimize briquetting process in term of processing parameters or briquetting machines, many researchers have carried out investigations into modelling of biomass briquetting. For example, Mandavgane and Venkatesh [8] developed artificial neural networks for modelling of properties of bio-briquettes like ash, volatile matter, relative moisture and calorific value as a function of compositions of briquettes. Artificial Neural Networks (ANN) is part of black box modelling technique, which had been used for estimation of properties of bio-briquettes. In the work, multiplayer perception (MLP), ANN with Generalized Delta Rule (GDR) based learning was developed for estimation of properties of bio-briquettes as a function of composition. The most accurate ANN model was arrived at, after number of trials and errors as done in earlier attempts by Mandavgane et al., 2006 [9]. The biomass feed stocks used were cow dung, sawdust, rice and tree leaves. There was straight line relationship between the actual and predicted values of percentage ash content, relative moisture content, volatile matter and calorific values. This reveals the accuracy and success of the ANN models developed, which have high accuracy level of between 98-99.5%.

Hernandez et al. (2004) [10] attempted to find the levels of factors that provide optimum responses in terms of quality of products and cost in the densification of a cattle feed diet based on corn crop residues (62%). The responses (dependent variables) defined according to the application were density and durability as those variables represent quality of product and specific energy consumption as a cost parameter. To attain this goal, an optimization procedure for multiple response problems was used. This procedure uses the response surface methodology (RSM) and the desirability function. The RSM is popular in the study of the food-extrusion processes [11]. RSM is a collection of statistical techniques that are useful for modelling and analysis of process [12]. Through the use of optimization process, the optimum values arrived at were 13% moisture content, $102^{O}C$ die temperature, $28N/m^2$ compression pressure and particle size 9.5mm.

Mani et al. (2003) [13] developed a numerical model using Discrete Element Method (DEM) to study the compaction characteristics of biomass during densification. DEM is a numerical modelling method that makes use of contact mechanics between the particles and the wall to model the dynamics of assemblies of particles [14]. In the work, DEM was used to model the compaction behaviour of corn stover grinds using particle flow code in 3D (PFC^{3D}) software. The specific properties of biomass particles such as particle size distribution, particle density, particle stiffness, particle-particle friction and particle-wall friction were incorporated into the model. A simple contact bond model was developed to produce the compacted mass.

The objective of this research was to develop predictive models for briquetting of corncob from two species of maize by using regressive technique to establish the relationship between the particle sizes, compaction pressures and percentage binder ratios by weight. The relationship developed was used to predict response parameters such as density, relaxed density, compaction as well as density and relaxation ratios. The relationship was also used to predict briquettes stability through the determination of percentage axial and lateral expansions.

II. Materials and Methods

Two species of corncobs were obtained from farm dumps. They were sun-dried and their moisture contents were determined using ASAE S269.4 2003 [15]. The corncob residues were subjected to size reduction process through the use of hammer mill equipped with different screens in compliance with procedure described in ASAE 424.1 2003 [16]. Three particle sizes S_1 (4.70 mm), S_2 (2.40 mm) and S_3 (0.60 mm) representing coarse, medium and fine series respectively were selected. The bulk density of the unprocessed materials and relaxed briquettes were determined using ASAE standard. Starch mutillage (binder) was added to the residues at 20 (B_1), 25 (B_2), and 30 % (B_3) by weight of the residue. A briquetting machine specially designed and fabricated for formation of briquettes was filled with a fixed charge of residue and compressed manually. Pressures of 2.40 (P_1), 4.40 (P_2) and 6.60 (P_3) MPa were separately applied for each briquette formation. A dwell time of 120 seconds was observed for the briquettes during formation. The initial, maximum and the relaxed densities of the briquettes were determined using the mould dimension, the relaxed briquette's dimension and ASAE standard method of determining densities. Also determined were the compaction, density and relaxation ratios of the formed briquettes. Briquette stability through the calculation of percentage axial and lateral expansions was also determined. These experimental data were subjected to regression analysis (Regression analysis provides a simple method for investigating functional relationships among variables). A statistical package SPSS version 11.0 was used for this analysis.

The process parameters examined in this work were % binder ratio (B), compaction pressure (P), and particle size (S). The output (response) variables are the physical properties of the briquettes. These output variables are as follows:-

i) Maximum Density ii) Relaxed Density iii) Compaction Ratio iv) Density Ratio
v) Relaxation Ratio vi) Axial Expansion vii)Lateral Expansion

2.1 Model Development

Let the functional relationship between the output variables and the set of input parameters as follows:-

i) Maximum Density = f [% Binder ratio (B), Compaction pressure (P), Particle size (S)] + C_1 (1)
ii) Relaxed Density = f [% Binder ratio (B), Compaction pressure (P), Particle size(S)] +C_2 (2)
iii) Compaction Ratio= f [% Binder ratio (B), Compaction pressure (P), Particle size (S)] +C_2 (3)
iv) Density Ratio = f [% Binder ratio (B), Compaction pressure (P), Particle size(S)] + C_4 (4)
v) Relaxation Ratio = f [% Binder ratio (B), Compaction pressure (P), Particle size(S)] + C_5 (5)

vi). Axial Expansion = f [% Binder ratio (B), Compaction pressure (P), Particle size(S)] + C_6 (6)

vii) Lateral Expansion = f [% Binder ratio (B), Compaction pressure (P), Particle size (S)] +C_7 (7)

Having established the different relationship of each input variable with the output variables, multiple regression analysis was done to estimate the coefficients of model factor.

After formulating equations 1 to 7, simulations of the equations were done and the results were compared with the experimental to show the practicability of the model. The simulation was conducted on Mat Lab 6.50 version of Mathworks Inc.NY, which is a mathematical simulator.

III. Results and Discussions

The estimated coefficients of the fitted models for output variables obtained from regression analysis of experimental data are presented in Table 1.

Table 1: Estimated Coefficients of the fitted Models for output variables based on t- statics for corncob briquettes from white and yellow maize

	Model Factor	Coefficients		t-values	
		White	**Yellow**	**White**	**Yellow**
Maximum Density (kg/m³)	Constant C_1	797.50	624.82	11.57	29.61
	B	12.289	-6.4333	- 4.95	-8.47
	P	23.121	16.807	4.20	9.96
	S	24.693	48.790	4.09	26.40
	R^2 = 0.72 s = 52.6 White		**R^2 = 0.97 s =16.11 Yellow**		
		White	**Yellow**	**White**	**Yellow**
Relaxed Density (kg/m³)	Constant C_2	439	438.78	20.05	16.96
	B	1.922	-1.1556	- 2.44	-1.24
	P	4.699	6.614	2.69	3.20
	S	17.940	-18.224	- 9.36	-8.04
	R^2 = 0.81 s = 16.70 White		**R2 = 0.77 s = 19.75 Yellow**		
		White	**Yellow**	**White**	**Yellow**
Compaction Ratio	Constant C_3	4.4447	4.1675	7.92	16.95
	B	- 0.10989	-0.09366	- 5.44	-10.59
	P	0.12874	0.096444	2.87	4.91
	S	0.47391	0.59603	9.65	27.69
	R^2 = 0.85 s = 0.4283 White		**R^2 = 0.98 s = 0.1877 Yellow**		
		White	**Yellow**	**White**	**Yellow**
Density Ratio	Constant C_4	0.57774	0.70926	11.27	13.40
	B	0.006222	0.004333	-3.37	2.27
	P	- 0.010804	-0.00588	- 2.64	-1.39
	S	- 0.046532	-0.07232	-10.36	-15.60
	R^2 = 0.84 s = 0.03915 White		**R^2 = 0.92 s = 0.0401 Yellow**		
		White	**Yellow**	**White**	**Yellow**
Relaxation Ratio	Constant C_5	1.8643	1.35693	8.25	13.64
	B	- 0.024889	-0.00866	- 3.06	-2.42
	P	0.03834	0.014223	2.12	1.79
	S	0.15862	0.201754	8.01	23.15
	R^2 = 0.77 s = 0.1726 White		**R2 = 0.96 s = 0.07597 Yellow**		
		White	**Yellow**	**White**	**Yellow**
Axial Expansion (%)	Constant C_6	- 4.152	--4.590	- 3.57	**-3.93**
	B	0.29122	0.27656	6.95	**6.59**
	P	- 0.50428	-0.39655	- 5.42	**-4.25**
	S	- 0.8433	-0.6871	8.28	**6.75**
	R^2 = 0.86 s = 0.8883 White		**R^2 = 0.82 s = 0.8909 Yellow**		
		White	**Yellow**	**White**	**Yellow**

Lateral Expansion (%)	Constant C_7	- 0.7107	-0.6127	-1.64	-2.30
	B	0.09778	0.074667	6.29	8.10
	P	- 0.20367	-0.13270	-5.90	-6.48
	S	0.18032	0.08339	4.76	3.72
	R^2 = 0.81 s = 0.3300 White		**R2 = 0.84 s = 0.1965 Yellow**		

From Table 1, the regression analyses for the seven models for briquettes from corncob from white maize had regression coefficients r = 0.72, 0.81, 0.85, 0.84, 0.77, 0.86 and 0.81 for the maximum density, relaxed density, compaction ratio, density ratio, relaxation ratio, axial expansion and lateral expansion respectively, while the corresponding value for briquettes fro yellow maize are 0.97, 0.77, 0.98, 0.92, 0.96, 0.82 and 0.84. All these values are significant at 95% level implying good model fit. It was also observed that regression coefficients obtained for briquettes produced from corncob from yellow maize are relatively higher than its yellow maize counterpart. Following the regression analysis to estimate the response models and the accompanying statistics, the developed models for maximum density, relaxed density, compaction ratio, density ratio, relaxation ratio, axial expansion and lateral expansion are presented in equations 8 – 14 for corncob from white maize, while equations 15 to 21 give corresponding models for briquettes produced from corncob from yellow maize. These are the empirical models obtained from multiple regression analysis.

i) Maximum density $= 797 - 12.3B + 23.1P + 24.7S$ (8)

ii) Relaxed density $= 439 - 1.92B + 4.70P + 17.9S$ (9)

iii) Compaction ratio $= 4.44 - 0.11B + 0.129P + 0.474S$ (10)

iv) Density ratio $= 0.578 - 0.0062B + 0.0108P + 0.465S$ (11)

v) Relaxation ratio $= 1.86 - 0.0249B + 0.0383P + 0.159S$ (12)

vi) Axial Expansion $= -4.15 + 0.291B - 0.504P + 0.843S$ (13)

vii) Lateral expansion $= -0.711 + 0.0978B - 0.204P + 0.180$ (14)

viii) Maximum density $= 625 - 6.43B + 16.8P + 48.8S$ (15)

ix) Relaxed density $= 439 - 1.16B + 6.61P + 18.2S$ (16)

x) Compaction ratio $= 4.17 - 0.0937B + 0.0963P + 0.596$ (17)

xi) Density ratio $= 0.709 - 0.00433B + 0.00588P + 0.0723S$ (18)

xii) Relaxation ratio $= 1.36 - 0.00867B + 0.0142P + 0.202S$ (19)

xiii) Axial Expansion $= -4.59 + 0.277B - 0.397P + 0.687S$ (20)

xiv) Lateral expansion $= -0.613 + 0.07478B - 0.133P + 0.0834S$ (21)

Where
B = Percentage binder ratio by weight (%)
P = Compaction pressure (MPa)
S = Particle size (mm)

3.1 Simulation and Validation of Models

The summary of the t-test for the simulated models for the seven physical properties examined in this study is presented in Table 2 at 95% significant level for briquettes formed.

Table 2: Summary of T-calculated and t-test for Experimental and Simulated Models for Briquettes from Corncob from white Maize and yellow Maize

Source of Variation	T-value Calculated		t-value Critical		Remark
	White	Yellow	White	Yellow	
Maximum Density	0.499	0.50	1.675	1.674	No Significant Difference
Relaxed Density	0.499	0.49	1.675	1.674	No Significant Difference
Compaction Ratio	0.50	0.49	1.674	1.674	No Significant Difference
Density Ratio	0.50	0.50	1.673	1.675	No Significant Difference
Relaxation Ratio	0.499	0.50	1.675	1.674	No Significant Difference
Axial Expansion	0.499	0.50	1.674	1.674	No Significant Difference
Lateral Expansion	0.499	0.49	1.675	1.675	No Significant Difference

For all the physical properties examined in this work, the values of T-calculated are less than t-Critical for briquettes produced from corncob for both species. The implication of this is that, there is no significant difference between the experimental and the simulated models for both species (Table 2). Figures 1 - 4 showed the comparison between the experimental and simulated properties of the briquettes for the two of response parameters, the maximum and relaxed densities for both species examined in this work.

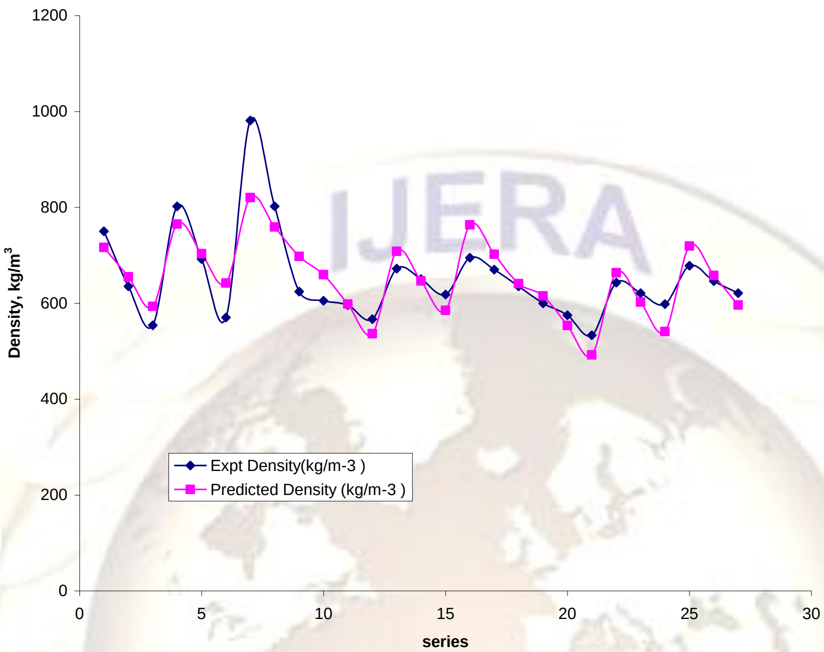

Figure 1: Comparison of Experimental and Simulated Maximum Density for Briquettes from Corncob from white Maize

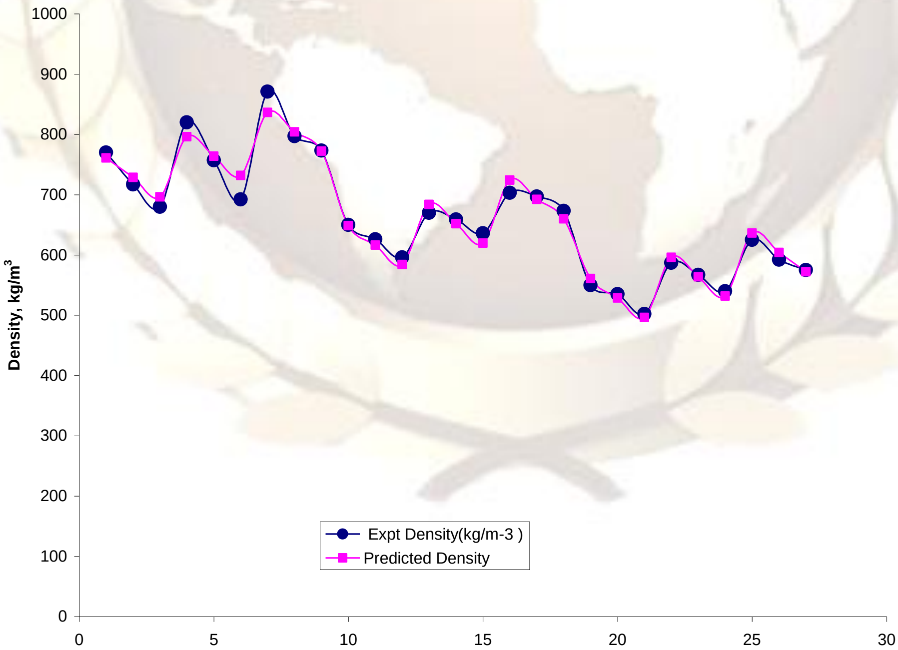

Figure 2: Comparison of Experimental and Simulated Maximum Density for Briquettes from Corncob from yellow Maize

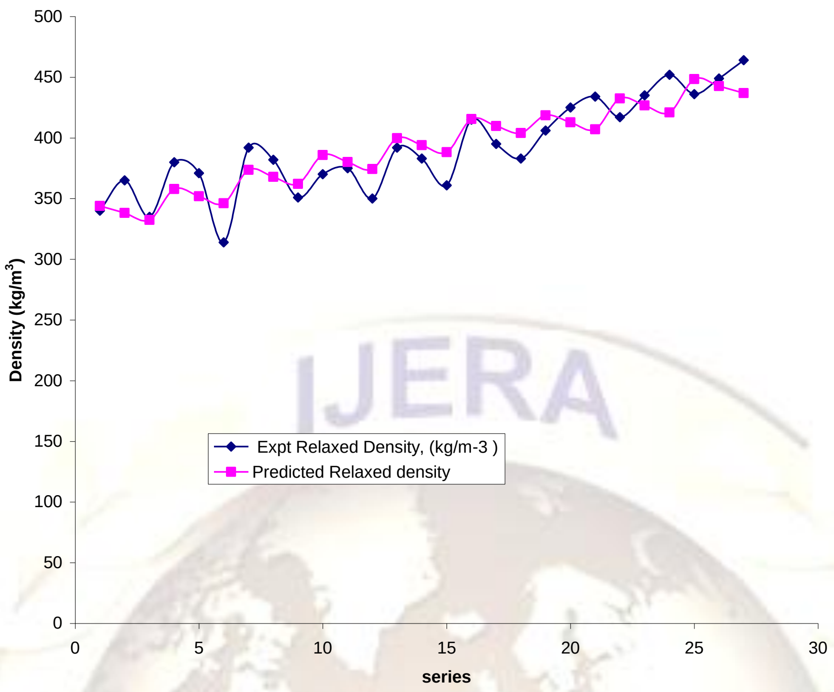

Figure 3: Comparison of Experimental and Simulated Relaxed Density for Briquettes from Corncob from white Maize

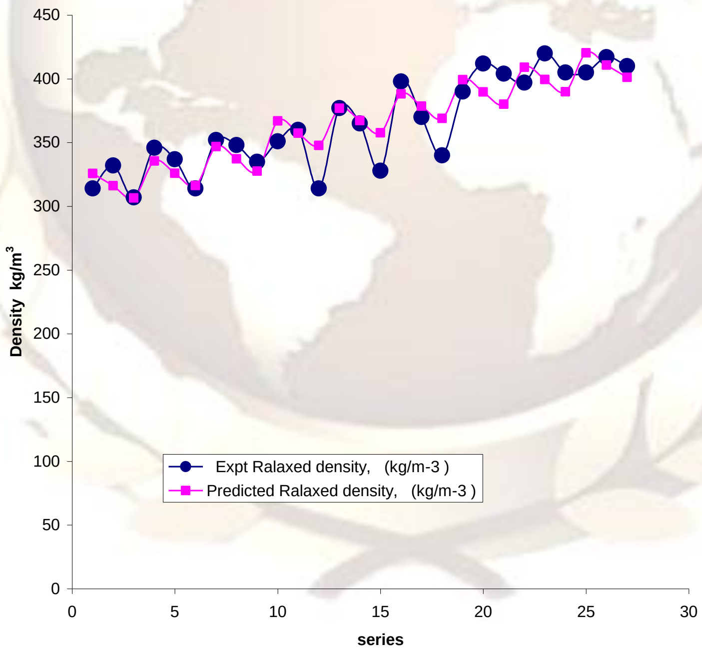

Figure 4: Comparison of Experimental and Simulated Relaxed Density for Briquettes from Corncob from yellow Maize

IV. Conclusions

Fourteen (14) mathematical models were developed, seven (7) each for briquettes from white and yellow corncobs. The regression analyses for the seven models for briquettes produced from corncob from white maize had regression coefficients r = 0.72, 0.81, 0.85, 0.84, 0.77, 0.86 and 0.81 for the maximum density, relaxed density, compaction ratio, density ratio, relaxation ratio, axial expansion and lateral expansion respectively. The corresponding values of regression coefficient for briquettes produced from corncob from yellow maize are 0.97, 0.77, 0.98, 0.92, 0.90, 0.82 and

0.84. All these values are significant at 95% level implying good model fit.

Since t-statistics is less than t-Critical both at one and two-tail with 95% confidence level for all the physical parameters examined, the study concluded that there is no significant difference between experimental and predicted results. Hence, all the developed models are reliable.

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