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ESTIMATION OF HIGH HEATING VALUE OF SOME AGRICULTURAL WASTE BLENDS

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Abstract

Biomass resources are renewable and sustainable energy sources. The efficient use of biomass energy will help in mitigating the global energy crisis. Adequate understanding of the physicochemical properties of biomass is essential for the study of the biomass potentials and very crucial for its utilization for fuel production. A high heating value is a key parameter to assess the energy content of different biomass feedstock. In this study, proximate analyses of biomass materials (groundnut shell, corn cob and Palm Oil Empty Fruit Bunch fibre) which are mainly agricultural residues and their blends. The effect of their components mixture on high heating value was determined based on some established empirical model equations. The calculated net heating value (NHV) and high heating value (HHV) of the feedstock and their blends are in the range of 16.16 -18.51MJ/kg. The results revealed that the estimated energy values using the model equations were good for solid fuel production especially when the corn cob and ground nutshell are in high percentage.

Keywords: *Groundnut Shell; Corn cob; EFB; Proximate analysis; HHV; NHV*

Introduction

Biomass is the most important source of benign energy production which can be obtained from cheaply and renewable sources [1]. Biomass combustion technology for energy production is economically effective and feasible for domestic application especially in rural dwellers in Nigeria as it is cheap, clean and renewable [2]. However, the combustion of biomass as fuel has lots of environmental and economic advantages [3]. Thermochemical conversions comprise; combustion, pyrolysis and gasification are important and sustainable processes for the conversion of agricultural residue into fuels [4]. The calorific value of biomass is an indication of the energy chemically bound in it and the combustion process, it can be converted into heat energy [5].

Currently, the global energy crisis is constantly increasing as a result of its increase in energy demands for our modern society [6]. Approximately, 90% of the world's energy consumption comes from fossil fuels which cause greenhouse gas emissions and global warming. However, these energy resources are limited and eventually get depleted [7]. To address this trying condition, countries have heavily promoted the use of alternative fuel sources for fuel [8]. The benefits of using this fuel for small-scale thermochemical conversion are clear, as they are renewable resources and can provide inexpensive auxiliary fuel [9].

Biomass application for fuel in thermal uses needs Information about its heating value [10]. The heating value reveals the energy content of fuel in a standardized fashion which is often expressed as the higher heating value HHV or lower heating value LHV [10]. The gross heating value (GHV) is the heat released from the complete combustion of a unit volume of fuel leading to the production of water vapour and its eventual condensation. Thus, is the total energy released from the complete combustion of a biomass sample [10]. The LHV, also known as the net heating value (NHV), does not envisage this latent heat of water contained by fuels.

The experimental or direct determination of the heating value of a biomass sample using an adiabatic bomb calorimeter is arduous and required expensive instrumentation. Similarly, the determination of its elemental composition from the ultimate analysis is also unwieldy and requires expensive instrumentations. Thus, proximal composition for calculation of the HV is can be a good alternative [11]. The proximal analysis and elemental analysis are methods used to determine the percentage weight of moisture, volatile material (VM), fixed carbon (FC) and ash whereas elemental weight percentage, of C, H, N, O, and S present in the sample in the sample [10]. Over some decades, researchers focused on empirical correlations between the high heating value of biomass fuels and its proximate/ultimate data with special emphasis on agricultural wastes [12].

Erol *et al*. [11] formulate 13 new different equations for estimating the calorific values using 20 different biomass samples from their proximate analyses data. Thus, the equations were correlated with least squares regression analyses (0.829 to 0.898) with standard deviations (0.4419 and 0.5280). The equations will be used to measure net heating values and high heating values. Correspondingly, a correlations equation was developed based on proximate analysis data to predict HHV of coal (as-received basis) using proximate analyses of 250 coal samples. Hence, its significance lies in the involvement of all the major variables (moisture and ash contents) affecting the HHV [13].

The high cost of fossil fuels globally causes the Nigerian citizens to be cutting down trees for fuels and charcoal production for domestic energy demand, especially among rural dwellers. These posed serious environmental challenges. In this study, three agricultural biomass blends were formed to study the effect of their mixing ratio on high heating value based on established empirical correlation equations using their proximate and ultimate analyses data. Also, their energy value for onward conversion into solid fuels was investigated.

Materials and Methods

Biomass Sample Collection

The biomass samples used in this work were palm oil empty fruit bunch fibre which was obtained from Benue state, Nigeria, corncob and ground nut shells in Kara market, Sokoto state, Nigeria. The samples were grounded and sieved through 60meshe to retain uniform size. Mixture design of experimental design matrix using Minitab Software Version 17. The design runs are shown in Table 1.

Table 1: Mixture Design Matrix of the Sample

RunOrder	EFB (g)	G. SHELL (g)	CORNCOB (g)	Total (g)
1	1	4	1	6
2	1	1	4	6
3	4	1	1	6
4	0	0	6	6
5	6	0	0	6
6	0	6	0	6
7	2	2	2	6

Proximate Analysis

Proximate analysis (which includes moisture, ash, volatile matter and fixed carbon content) was determined for the biomass blends according to the ASTM D4442-16 method. The volatile matter and ash content were determined by the ASTM E1755-01 and ASTM E872-82 respectively. The fixed carbon content in the biomass samples was calculated by difference using equation 1. Equally, total organic matter (OM) was calculated using equation 2 [14].

$$FC = 100 - (\%MC + \%Ash + \%VM) - 1$$

Where FC = Fixed carbon content, % MC = Percentage moisture content, $\%Ash$ Percentage Ash Content, and % VM = Percentage Volatile Matter.

$$OM = \ 100 - \%Ash - - - - - - - - -2$$

Determination of High Heating Value and Ultimate Analysis

The net heating value (NHV) and high heating value (HHV) was calculated from the proximate analysis conducted on the biomass samples blends using equation (3) and (4) developed by Erol *et al*. [11] and Yin, [9].

NHV = -116 – 1.33[Ash] – 0.005[VM] + 1.92[VM + Ash] – 0.0227[VM x Ash] – 0.0122$[VM]^2$ + 0.0299$[Ash]^2$ + 6133$[OM]^{-1}$ – 0.82$[Ash]^{-1}$ ---------------------------------3

$$HHV = 0.1905VM + 0.2521FC - - - -4$$

Similarly, the blend ultimate analysis was calculated from the proximate analysis as well using equations 5, 6 and 7 as established by Parikh [14], while the high heating value using was calculated using equation (8) developed by Yin[9] from the ultimate analysis.

$$C = 0.637FC + 0.455VM - - - - - - -5$$

$$H = 0.052FC + 0.062VM - - - - - - -6$$

$$O = 0.304FC + 0.476VM - - - - - - -7$$

$$HHV = 0.2949C + 0.8250H - - - -8$$

Results and Discussion

Proximate Analysis

The results of the proximate analysis of the blends are presented in Fig. 1. The results in Fig. 1 and Table 3 revealed that the EFB fibre has the lowest MC while the Corncob has the lowest. But for the ash content, the EFB has the highest while corncob lowest. On the VM corncob has the highest percentage while EFB has the lowest. Moisture content is a percentage of water content present in a biomass sample. The moisture was observed to be in the range of 4.0 to 9.3 %, with the lowest recorded in palm oil empty fruit bunch (EFB) fibre and the highest in corncob waste. High moisture content shows the combustibility of the samples [15]. Volatile matter of biomass is condensable vapour and permanent gases released when the biomass is heated to 925°C for a few minutes [16]. The volatile matter obtained from the blends is in the range of 57.66 – 83.66 % with the lowest value reported in EFB and the highest value by the mixture of EFB, groundnut shell and corncob in the ratio of (4:1:1). High volatile matter ascertains ease in ignition [17]. On the other hand, understanding the relationship between the volatile matters of biomass with its heating value is very complex as a higher percentage of volatile matter constituents are non-combustible fractions [3]. This could be evidenced in Tables 3 & 4, with groundnut shell and corncob having high volatile matter (Fig. 1) but recorded low heating values from both proximate and ultimate results. Fixed carbon (FC) is the solid combustible residue left when biomass is heated and volatile matter were expelled. FC indicates a longer combustion time of a biomass sample, leading to an increase in the HHV of the sample [18]. The lowest value of fixed carbon of 4.41% was observed for EFB, ground nut shell and corncob blend (4:1:1 ratio) while the highest value of 29.68% was observed from EFB. The fixed carbon content of biomass can be easily connected with the calorific value as it has a positive effect on the energy potential of biomass [19]. This can be confirmed from the results in (Tables 3 & 4), with EFB and a mixture of (EFB, groundnut shell and corncob) in the ratio of 1:1:4 recording the highest heating value of 18.47 and 18.51MJ respectively. The slight difference in heating values observed may be attributed to the difference in the ash content percentage [20].

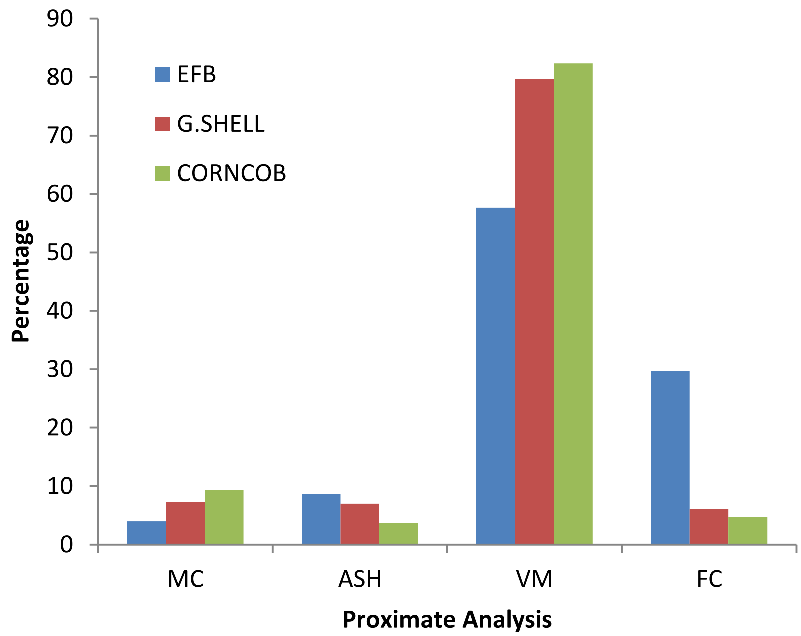

Figure 1: Proximate analysis of the biomass

Ash content is a percentage of non-combustible inorganic minerals present in a substance. The ash content obtained is in the range of 3.33 to 8.66 %. In all the three biomass samples investigated, corncob has the lowest ash percentage compared to groundnut shell and EFB. The differences in ash content among the feedstock may be attributed to the nature of the biomass, soil variations and environmental effects, which affect the ash content and properties of the biomass [21]. Ash has not only had an inert effect on the calorific value of a fuel but also shows some negative effects on the apparent heat obtained from burning the biomass [22]. This could be the reason for the high and low neat heating values (NHV) recorded by corncob and EFB (Table 2).

Table 2: Mixture Design Matrix of Proximate Analysis.

Run Order	EFB (g)	G. SHELL (g)	CORNCOB (g)	MC (%)	ASH (%)	VM (%)	FC (%)	OM (%)
1	1	4	1	5.66	3.33	81.00	9.97	96.67
2	1	1	4	6.66	3.33	67.66	22.31	96.67
3	4	1	1	5.60	6.33	83.66	4.41	93.67
4	0	0	6	9.30	3.66	82.33	4.71	96.34
5	6	0	0	4.00	8.66	57.66	29.68	91.34
6	0	6	0	7.30	7.00	79.66	6.04	93.00
7	2	2	2	7.30	4.33	83.00	5.37	95.67

High Heating Value (HHV) Analysis

HHV is an energy density of a feedstock and it is often termed a calorific value. It is defined as the quantity of heat produced by the burning of a specific amount of biomass [13]. The HHV in (Table 3 and 4) were calculated from the proximate and elemental composition based on empirical correlations and was expressed in MJ/kg. Since the biomasses have different fuel properties, the HHV changed considerably for the individual samples and their blends. The calculated heating value was in the range of 16.16 - 18.51 MJ/kg and the values were in good agreement with the other biomasses reported in the literature [23]

Table 3: Estimated High Heating Value and Net Heating Value from Proximate Analysis Results

RunOrder	EFB(g)	G. SHELL(g)	CORNCOB(g)	NHV (%)	HHV (%)
1	1	4	1	18.44	17.94
2	1	1	4	18.10	18.51
3	4	1	1	17.08	17.05
4	0	0	6	18.12	16.87
5	6	0	0	16.92	18.47
6	0	6	0	17.90	16.70
7	2	2	2	17.77	17.17

Table 4: Estimated Elemental Analysis Ultimate data and High Heating Value

RunOrder	EFB(g)	G. SHELL(g)	CORNCOB(g)	C(%)	H(%)	O(%)	HHV(MJ/K)
1	1	4	1	43.21	5.54	41.59	17.31
2	1	1	4	44.99	5.36	38.99	17.69
3	4	1	1	40.87	5.42	41.16	16.52
4	0	0	6	40.46	5.35	40.62	16.35
5	6	0	0	45.14	5.11	36.46	17.53
6	0	6	0	40.09	5.25	39.75	16.16
7	2	2	2	41.19	5.43	41.14	16.62

Figure 2, presents elemental composition and HHVs for the three biomass samples studied and it revealed that HHVs are a factor of feedstock carbon content. This confirms the findings reported by El-Quhuda [24] that, carbon is one of the main heat-producing elements and biomass with high carbon tends to have higher HHV. A high percentage of carbon and hydrogen and low oxygen content in biomass is preferred as it results in better properties of biofuels [25].

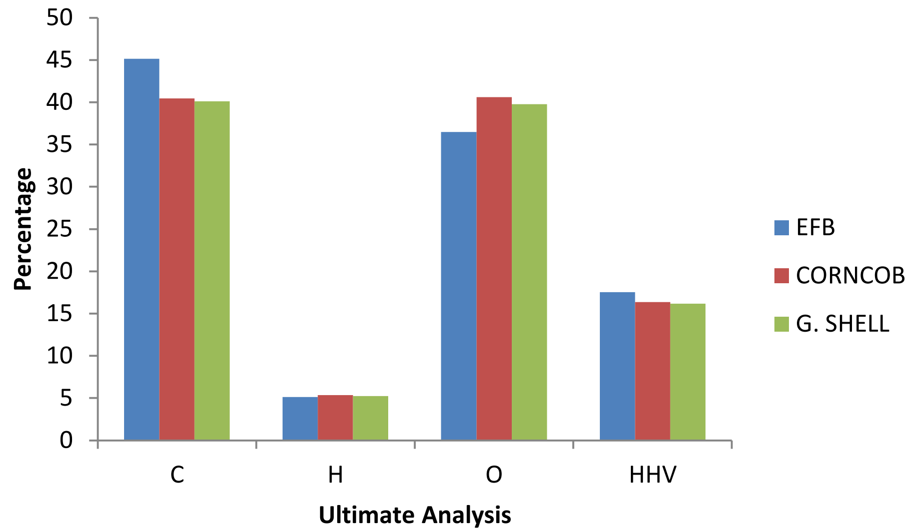

Figure 2: Estimated Elemental composition and HHV of the Sample

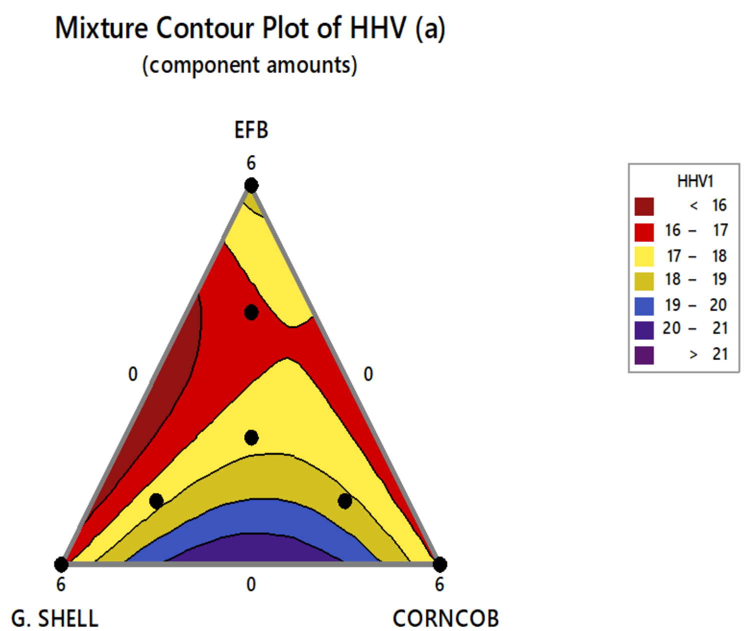

Figure 3a: Contour Plot of HHV from Estimated from Proximate Data

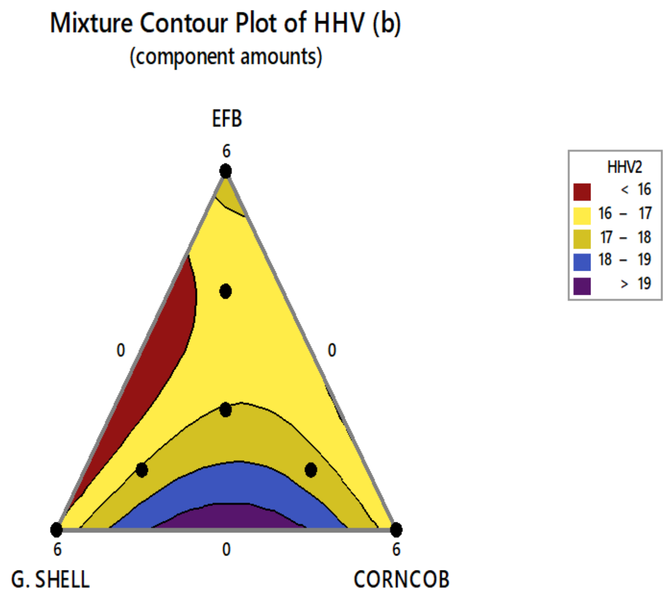

Figure 3a: Contour Plot of HHV Estimated from Ultimate Data

The figures (3a and b) show a mixture contour plot where the area for there is significant synergy when these three samples were mixed. HHV of the samples was observed to be greater between Ground nut shell and Corncob blends. But, drastically reduced when groundnut and EFB fibre were mixed. Also, the HHV falls within the range of 16-17MJ/K when EFB fibre and Corn corncob are mixed. Although, the blends of EFB fibre show low HHV content, 18-19MJ/K of HHV was achieved when a 100% EFB fibre sample was used. Thus, this shows that the synergy between the samples and with EFB fibre does not give high HHV. The HHV of a biomass sample is the sum of energy discharges when it is completely burnt in adequate oxygen [26]. Thus, it is one of the most important biomass energy conversion properties [27]. However, the heating value of biomass is low when compared to most fossil fuels [28].

Conclusion

The results obtained from this study reveal that the EFB fibre, Corncob, and groundnut shell and their blends have a good high heating value that can be used directly as solid fuel. The study also established that these three biomass samples when mixed in different proportions have a significant influence on the high heat value content of the substrates.

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