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Effect of Moisture on the Thermal Capacity of some Agricultural Wastes

Burubai,W[1]. and Okpala, A.N[2].
[1.]*Department of Agricultural and Environmental Engineering,*
[2.]*Department of Mechanical Engineering Faculty Of Engineering,*
Niger Delta University Wilberforce Island, Bayelsa State, Nigeria

Abstract: The effect of moisture content on the high heating value (calorific value) of groundnut shells, corn cobs, coconut shells and palm kernel shells were investigated using a bomb calorimeter. Results show that, generally, high heating values of all test samples decreased with increase in moisture level. Heating values of 18.795MJ/Kg at 9.34% moisture, 21.775MJ/Kg at 8.93% moisture, 39.972MJ/Kg at 8.26% moisture and 42.826MJ/Kg at 7.58% moisture were recorded for groundnut shells, corn cobs, coconut shells and palm kernel shells respectively. These heating values decreased to 9.65MJ/Kg, 12.25MJ/Kg, 15.421MJ/Kg and 16.553MJ/Kg at 24.0% moisture level for groundnut shells, corn cobs, coconut shells and palm kernel shells respectively. However, at all moisture levels, palm kernel shells had the highest heating values and were followed by coconut shells. Thus, with appropriate technology, these agricultural wastes could be converted to useful energy and also ensure a cleaner environment.

Keywords: Calorific value, wastes, moisture, energy generation, environment.

I. INTRODUCTION

Agricultural wastes could be defined as those excesses of agricultural production that have not been effectively and fully utilized. This includes crop residues, animal refuse, processing wastes and, perhaps, forest biomass. However, in an attempt to curb food insecurity in developing countries like Nigeria, agricultural production has increased recently and this has led to an increase in the volume of different types of agricultural waste, by-products and residues. It is estimated that over 18 million tones of such wastes are produced annually in Nigeria in the forms of straws, stalks, husks, cobs, shells, saw dusts, peels etc (Usman *et al*, 2014) and globally, over 998 million tones of agricultural waste is generated annually (Agamuthu, 2009). However, greater percentage of these wastes remains un-utilized and their disposal and management is a source of environmental concern to developing nations.

Currently, in Nigeria, the most common waste management approaches adopted are methods of concentration and or relocation of wastes. Methods of recycling, reprocessing and utilization of the waste in positive manner offers the possibility of returning the excesses to beneficial use. Beneficial options of agricultural wastes include uses as fuels, building materials, animal feeds, paper and board, medicine etc.

In terms of energy production (fuel), different agricultural wastes have been traditionally used as fuel either as solid, liquid or gaseous products. The processes for converting such organic materials into fuels include both dry (non-biological) and wet (biological) processes. These processes are based on thermal, chemical and enzymatic conversion methods (Sahay and Singh, 2014).

The dry (non-biological) process is the burning of waste materials in excess of air with near complete combustion of the material. This has application in drying, steam production or electricity generation. Furthermore, agricultural waste can be dry burned to power internal combustion engines. They can also be dry heated in the absence of oxygen which results in destructive distillation with a chief product called charcoal. The charcoal can be used directly or as briquette fuel in cooking of food materials or in steam generation. But the choice of agricultural wastes for energy production depends on the thermal capacity (calorific value) of the waste materials which are in abundance in Nigeria.

Globally, it is a truism that energy is the key factor in the economic development of most countries today. And as the world adjusts itself to the increasing demand and rising cost of energy (fossil fuel), adopting the waste conversion into energy will not only create a safe and hygienic way of disposing the wastes, but turn it into a revenue earner and also contributing towards a better environment especially in Nigeria. It is therefore the objective of this study to investigate the thermal capacity (calorific value) of some agricultural wastes like groundnut shells, coconut shells, palm kernel shells, and corn cob as influenced by moisture content.

II. MATERIALS AND METHODS

Sample Preparation

4 kg each of groundnut shells, corn cobs, palm kernel shells and coconut shells were obtained from markets, dump sites and mills in Bayelsa State, Nigeria in November, 2015. The various samples were taken to the Food Processing Laboratory of the Niger Delta University in sack bags. At the laboratory, palm kernel shells, corn cobs and coconut shells were grinded using hammer mill while the groundnut shells were grinded with mortar and pestle. The initial moisture content of all samples was then determined by the oven method as recommended by ASAE Standard S368.41 (2000) at a temperature of 105^{o}C. The remaining samples were then conditioned to four other moisture levels (12.0, 16.0, 20.0 and 24.0% wb) by adding predetermined amounts of water and storing in a refrigerator in polyethylene bags at 10^{O}C for 24hours to equilibrate. The samples were then taken in ice-chest box to the Department of Petroleum Resources (DPR) laboratory in Port-Harcourt for analysis. However, the desired moisture content for all samples were obtained by adding calculated amounts of water using the re-wetting equation for biomaterials as

$$W = \frac{Wi(Mf - Mi)}{100 - Mf} \qquad 1$$

Where W is mass of water added (g), Wi is initial mass of sample (g), Mi is initial moisture content and Mf is the desired moisture content (%wb).

Procedure

As recommended by European Standard (EN) 14918(2009) and ASTM E870-82 (2006) for the determination of calorific value of solid biofuels, a standard device called bomb calorimeter (Parr 6220) was used for this experiment. This device burns a small mass of biomass in the presence of oxygen inside a sealed container. The heat released from the combustion is transferred to a mass of fluid that surrounds the container. The heating value is automatically generated by the calorimeter and considered as high heating value (gross heating value) at constant volume. The resulting gross heating value can be expressed based on dry mass content of the sample biomass as

$$HHVd = \frac{HHV}{1 - M} \qquad 2$$

Where HHVd is gross heating value of biomass, MJ/Kg of bone dry biomass, HHV is the gross heating value determined by the calorimeter, MJ/Kg and M is the moisture content of the biomass in decimal wet mass fraction.

Thus, 1.1g of each sample at the selected moisture levels were pelleted with a pellet press and carefully placed in the bomb with tweezers. The bomb was then transferred into the bucket, and closed. The calorimeter was then powered for five minutes and the heating values automatically displayed on the screen and were recorded. Ten replications were made at each moisture level for all samples.

III. RESULTS AND DISCUSSIONS

The results obtained from the calorimetric analysis of groundnut shell, palm kernel shell, coconut shell and corn cob are presented in Table 1. Results show that, generally, high heating value otherwise called calorific value decreased as moisture increased for all samples investigated.

Table 1: Calorific values of samples as influenced by moisture content

Groundnut shell			Palm Kernel Shell		
MC(%wb)	**HHV(MJ/Kg)**	**HHVd(MJ/Kg)**	**MC(% wb)**	**HHV(MJ/Kg)**	**HHVd (MJ/Kg)**
9.34	17.04	18.795	7.58	39.58	42.826
12.00	16.21	18.421	12.00	33.74	38.341
16.00	14.84	17.667	16.00	26.59	31.655
20.00	13.91	17.388	20.00	18.41	23.013
24.00	9.65	12.697	24.00	12.58	16.553
Coconut Shell			**Corn Cob**		
MC(% wb)	**HHV(MJ/Kg)**	**HHVd(MJ/Kg)**	**MC(% wb)**	**HHV(MJ/Kg)**	**HHVd(MJ/Kg)**
8.26	36.67	39.972	8.93	19.83	21.775
12.00	30.41	34.557	12.00	15.06	17.114
16.00	22.59	26.893	16.00	11.83	14.083
20.00	15.38	19.225	20.00	10.01	12.513
24.00	11.72	15.421	24.00	93.31	12.250

Groundnut shells

As indicated in Table 1, the gross heating value of groundnut shell was remarkably affected by moisture changes. At a moisture content of 9.34%, heating value of 18.795 MJ/Kg was recorded. But this heating value, steadily, declined to 12.697MJ/Kg at a corresponding moisture level of 24.0%. This reduction in heating value with increase in moisture could be attributed to the fact that, probably a portion of the heat of combustion is utilized in evaporating the contained moisture, and the heat of steam formed passes off with the flue gases unused. It is therefore highly desirable that for purposes of energy generation, the moisture content of groundnut shell be kept as low as possible when consistent with economy. Notwithstanding, the heating value of 18.795MJ/Kg at 9.34% moisture is comparable to the heating values of orange peels (19.42MJ/Kg), mango peels (16.09MJ/Kg) and yam peels (19.44MJ/Kg) as presented by Jekayinfa and Omisakin (2005). A regression of moisture content against gross heating value of groundnut shell is shown in Fig 1.

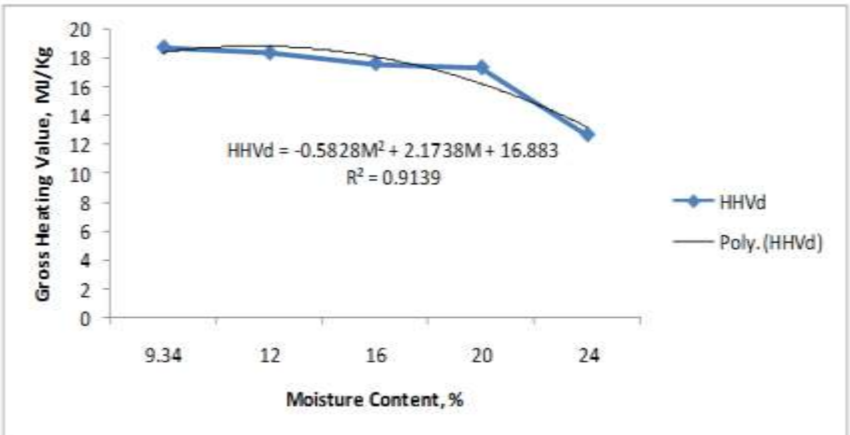

Fig1: Effect of moisture on heating value of groundnut shell

Corn Cob

The energy generation capacity (high heating value) of corn cobs as influenced by moisture content is presented in Table 1 above. Results show that heating values of corn cobs decreased with increase in moisture level. At 8.93% moisture, a high heating value of 21.775MJ/Kg was noted, but this heating value decreased to 12.25MJ/Kg at a corresponding moisture level of 24.0%. This decrease in heating value at high moisture levels is, perhaps, due to the negative effect of heat needed to evaporate moisture in the combustion of wet agricultural materials. However, the high heating value obtained here (21.775MJ/Kg) is similar to that of black walnut hull (21.193MJ/Kg) as reported by Jekayinfa and Omisakin (2005) but higher than rice hulls (13.39MJ/Kg) as investigated by Hsu and Luh (1980). A regression between moisture content and gross heating value of corn cob is presented in Fig 2.

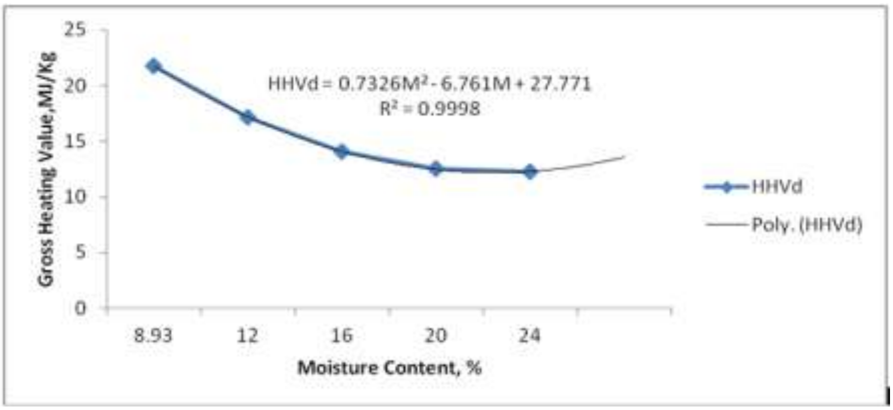

Fig 2: Effect of moisture on heating value of corn cob

Coconut shell

The high heating value of coconut shell as affected by moisture changes is shown in Table 1 above. A high heating value of 39.97MJ/Kg was observed at a moisture level of 8.26% but decreased to 15.421MJ/Kg at a corresponding moisture level of 24.0 %. Like the other samples, the decrease in heating value of coconut shell with increase in moisture level is, probably, because a portion of the heat of combustion is used up to evaporate the excess moisture in the sample. Notwithstanding, the recorded heating value of 39.97MJ/Kg is far higher than heating values of watermelon (23.47MJ/Kg) and cotton seeds (22.93MJ/Kg) as reported by Gravalos *et al*(2016). A relationship between moisture content and high heating value of coconut shell is indicated in Fig 3 below.

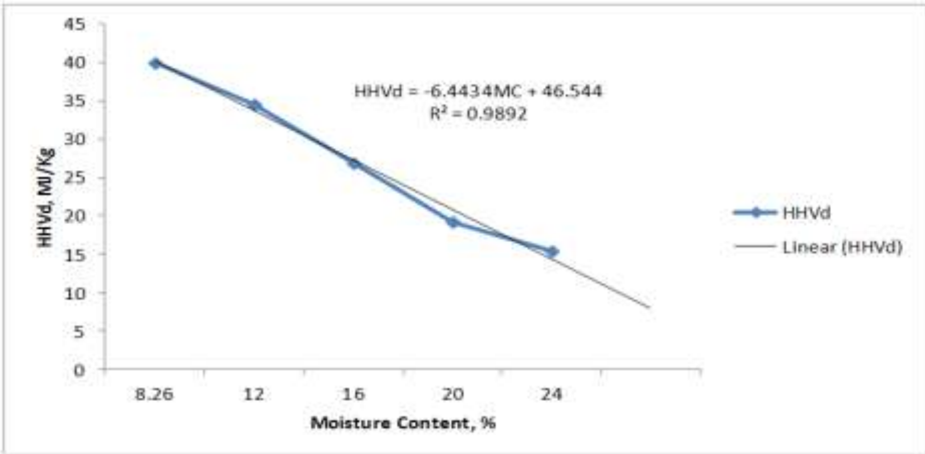

Fig 3: Effect of moisture on the high heating values of Coconut shell

Palm Kernel Shell

As depicted in Table 1 above, generally, the high heating values of palm kernel shell showed negative relationship with moisture increase. At a moisture content of 7.58%, a heating value of 42.83MJ/Kg was recorded. This heating value decreased to 16.55MJ/Kg at a corresponding moisture level of 24.0%. However, palm kernel shells recorded the highest heating values compared to the other test samples. The high heating value observed here is also higher than those of black walnut hull (Jekayinfa and Omisakin, 2005) and pomace (Kranzler et al, 1983). A relationship between moisture content and high heating values is indicated in Fig 4 below.

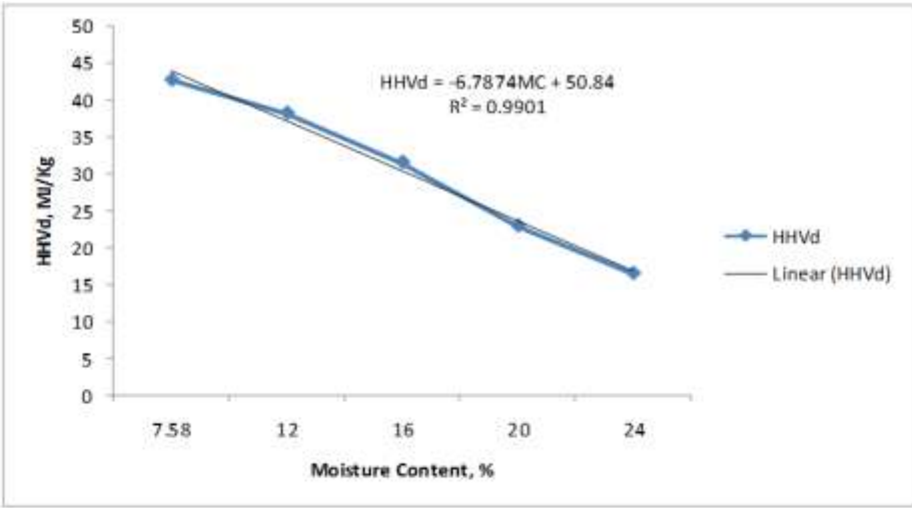

Fig 4: Effect of moisture on the high heating value of palm kernel shell.

Energy Density of the Samples

Energy density which is defined as a measure of the energy contained within a unit of fuel is an important parameter when investigating the calorific value of biofuels. It is a variable that will help users understand volumetric fuel consumption rates, the size of fuel storage required, the number of deliveries required and the total annual quantity of biofuel required. It is expressed in MJ/M^3, and can be obtained by multiplying the calorific value (MJ/Kg) by bulk density (Kg/m^3). Table 2 below shows the energy density of groundnut shell, corn cob, coconut shell and palm kernel shell. Results show that, at 12.0% moisture level, palm kernel shell had the highest energy density of 43124.83MJ/M^3, and was followed by coconut shell with 13962.24 MJ/M^3.

Table 2 Energy Density of samples at 12% moisture level

Sample	HHVd (MJ/Kg)	Bulk Density(Kg/m^3)	Energy Density (MJ /m^3)
Groundnut shell	18.44	85.50	1574.91
Corn cob	17.11	282.28	4829.81
Coconut shell	34.56	404.00	13962.24
Palm kernel shell	38.34	1124.80	43124.83

IV. CONCLUSIONS

From the results of this study, it can be concluded that agricultural wastes such as ground nut shells, corn cobs, coconut shells and palm kernel shells can generate huge amounts of energy (fuel) for our domestic consumption. However, the highest heating value was recorded in palm kernel shells and was followed by coconut shell.

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