Fuel Briquettes from Water Hyacinth-Cow Dung Mixture as Alternative Energy for Domestic and Agro-Industrial Applications

Dr. Frank. O. Oroka* and Akhihiero Thelma.E.**
*Agricultural Science Unit, Department of Vocational Education, Delta State University Abraka, Nigeria
E-mail of corresponding author: orkfra@yahoo.com
** Department of Chemical Engineering, Delta State University, Abraka, Nigeria
***ejiroakhihiero@yahoo.co.uk*

Abstract
The processing of agricultural wastes into biomass is a strategy towards the development of alternative energy sources. The study was undertaken to investigate the properties of fuel briquettes produced from a mixture of a water hyacinth and cow dung. Briquettes were manufactured with a manually-operated briquette press using four water hyacinth: cow dung mixing ratios (by weight), i.e., 100:0; 90: 10; 80: 20; and 70: 30. Results obtained showed that briquettes produced using 70:30 and 80:20 water hyacinth-cow dung ratios respectively exhibited the largest relaxed density on drying with values of 1157 and 1296 kg/m^3 respectively. Equilibrium moisture content (e.m.c) of the briquettes ranged between 10.5 % and 15.1%, with a gradual increase in e.m.c with increase in cow dung content. A reciprocal relationship was observed between compressed/relaxed density and relaxation ratio of the briquettes. The durability rating of all the briquettes exceeded 85%. Flue gas temperature ranged from 60.5 to 74.5 ^{0}C. Comparative water boiling tests indicated that water was brought to boiling within the range of 54 to 59 minutes. It was concluded that stable briquettes could be formed from water hyacinth mixed with cow dung and can be used as alternative energy source to kerosene and fuel wood.
Keywords: water hyacinth, briquette, cow dung, durability rating, bulk density

I. `Introduction

Increase in the energy demand and use in Nigeria due to rapid growth in population and industry has raised concerns about the economic and environmental impacts of power generation based on national energy sources. Kerosene and gas are the major cooking fuel. The majority of the people both in urban and rural Nigeria rely on kerosene stove for domestic cooking while only a few use gas and electric cooker even in the urban areas. As lighting fuel, it's common in virtually all homes in the rural areas and in majority households in the urban centers since electric power is grossly erratic and inadequate. The high cost of purchase and maintenance of both petrol and diesel powered generators have increased the use of kerosene in bush lamps and lanterns. Past experiences have shown that scarcity and increases in the prices of kerosene have often forced rural dwellers and urban poor to abandon the kerosene stove in favor of the comparatively cheaper fuel wood and charcoal which is seen as substitute source of energy. Hence small scale agro industries such as bakeries use fuel wood as source of energy.

Recent studies show that national demand for traditional energy (mostly fuel wood and charcoal) is 39 million tons per annum (about 37.4% of the total energy demand and the highest single share of all the energy forms). It is projected to increase to 91 million tons by 2030 Nigeria [1]. Thus there is urgent need for alternative energy sources to complement the petroleum products from the petroleum industry as well as conserve our forests.

Briquetting of the abundant biomass in Nigeria represents one of the possible solutions to the local energy shortages in the country. It constitutes a positive solution to the problem of increasing rates of desertification associated with high fuel wood consumption. Common among such biomass are water hyacinth (*Eicchornia crassipes* Solms, an aquatic weed has remained a threat to Nigeria coastal waters and inland water ways since 1980 and cow dung.

Biomass waste material is usually very bulky and has a very low density which makes it very difficult to be used in many types of burners and make its transportation also very uneconomical [2]. Densification of biomass is one of the solutions to this problem. Briquette quality is evaluated mainly by the briquette density [3]. If produced at low cost and made conveniently accessible to consumers, briquettes could serve as complements to firewood and charcoal and kerosene for domestic cooking and agro-industrial operations, thereby reducing the high demand for them. Besides, briquettes have been noted to have advantages over fuel wood in terms of greater heat intensity, cleanliness, convenience in use, and relatively smaller space requirement for storage [4]. A number of locally available materials have been found to be suitable for briquetting into fuel energy production. These include sawdust, cowpea chaffs, corncobs, and water hyacinth.

In a study to determine the physical attributes of briquettes from guinea corn (*Sorghum bicolor*) residue, using

starch mucilage as binder, it was observed that the briquettes could be kept safely for a period of six months without deterioration [5]. They also reported maximum density of briquettes ranging from 789 to 1372kg/m^3. In a related study, using waste paper and coconut husk admixtures in Nigeria, briquettes produced using 100% waste paper and 5:95 waste paper: coconut husk ratios respectively were shown to exhibit the largest minimal linear expansion on drying [6]. A reciprocal relationship was observed between compression/relaxed density and relaxed ratio of the briquettes. In a study, using two pairs of biomass viz. rice husk-water hyacinth and bagasse-rice straw, with cassava starch as a binder to produce cylindrical briquettes in Mahasarakham province, Thailand, results indicated that the mixing ratio significantly affected the compressive characteristics [7]. Densities of the briquettes produced were found to be in the range of 185-223 kg/m^3. The combustion test showed that the rice husk-water hyacinth briquette with the mixing ratio of 60:40 provided the highest flue gas temperature. CO contents emitted for all experiments were within the acceptable level [7].
The objectives of this study are to determine the physical properties of fuel briquettes made from water hyacinth using cow dung as co-mixture and binder at varying mixing ratios and to explore the potential of the biomass briquettes for cooking.

2. Materials and Methods

2.1 Raw Materials Preparation

Water hyacinth harvested from the nearby river was dried and chopped into very small sizes. The water hyacinth was reduced by a combination of choppers and milling machines. Cow dung was obtained from the abattoir situated in the community. The cow dung collected was sun dried and thereafter crushed mechanically using a mortar and pestle to ensure homogeneity. Chemical analysis of dry water hyacinth and cow dung were carried out to determine moisture content volatile matter, fixed carbon, and ash content using methods described [8]. The gross calorific value (GCV} of materials used for the briquettes were further estimated using the formula below as stated [9] :
Gross calorific value (GCV) = 20.0 x (1-A- M), where A is the percentage ash content and M is the percentage moisture content.

2.2. *Briquetting Procedure*

Chopped water hyacinth was allowed to stand for two weeks to partially decompose. The material was thoroughly mixed manually with dry cow dung until a uniformly blended mixture was obtained. Mixtures were prepared at the following water hyacinth: cow dung ratios, i.e., 100:0; 90: 10; 80: 20; and 70: 30, on a weight percent basis. The materials were mixed into soupy slurry in water. A fixed quantity of the slurry was put inside the briquette press made of a metal cylindrical mould with holes at the base of the mould with inner diameter of 10cm diameter and 30cm high, covered with a top metal plate and compressed manually to create round briquettes. A dwell time (duration of load application) of 90 seconds was observed for the briquettes during formation. One hundred replicate briquette samples was produced per batch from each mixture.

2.3 Briquette Quality Evaluation:

Determination of Bulk Density- Density is an important property of the fuel. High density products are desirable in terms of transportation, storage and handling. The bulk density of the briquetted biomass was determined by measuring dimensions and weights of 10 samples per batch. Weight measurements were performed with an electronic balance and the dimension of the samples were determined by using a vernier caliper. The average density was calculated and reported
Compressed density of the briquettes was determined immediately after removal from the briquetting machine as a ratio of measured weight over calculated volume.
To determine *dimensional stability*, the length of five representative briquettes from each production batch was measured at 0, 30, 60 and 1440 and 10,080 minute intervals. *Equilibrium Moisture content* (e.m.c.) of the briquettes was determined after 20 days of sun-drying at room temperature and relative humidity.
The *relaxed density* of the briquettes was also determined in the dry condition after 20 days.
The relaxation ratio was computed from the equation below:

$$\text{Relaxation ratio} = \frac{\text{Compressed density}}{\text{Relaxed density}}$$

The *durability* of the dry briquettes was determined with the aid of a durability tester, i.e., a dusttight 300 mm x 300mm x 450 mm enclosed box using the American Society of Agricultural Engineers (ASAE) standard method, S269.3. Test sample of five briquettes were tumbled for 3 minutes at 13 rev/min. This was conducted after 20 days of briquette formation. The weight of the solid briquettes remaining were then determined. The durability rating for each type of briquette will be expressed as a percentage of the initial mass of the material remaining in the box, expressed mathematically as follows:

$$\text{Durability (\%)} = \frac{\text{Weight of briquette before tumbling (kg)}}{\text{Weight of briquette after tumbling (kg)}}$$

Durability rating of 80-90% should be considered 'good' while 90 and above is considered 'very good' [10].
The *water resistance* of the dry briquettes was determined by immersing five samples each in a glass container filled with distilled water at room temperature for 3 hours and measuring the changes in length and diameter of each briquette. Each experiment was replicated thrice.
Combustion test: To evaluate combustion characteristics, 300 g of briquettes produced were placed over the hearth of the locally made stove and the burning tests were carried out at the atmospheric condition. Flue gas temperature was recorded during tests.
Cooking test (water boiling test): In other to evaluate the cooking potential of the water hyacinth: cow dung biomass briquettes, two (2) liters of water were boiled in a kettle on a cooking stove. The temperature versus time history was taken for the water boiling test.

3. Results and Discussions

3.1. Proximate analysis

Table 1: Proximate analysis, calorific values and density of sun-dried biomass used for briquettes production

Material	Volatile matter (%)	Fixed carbon (%)	Moisture content (%)	Ash (%)	Gross Calorific value (MJ/kg)	Density of unprocessed materials (kg/m^3)
Water hyacinth	56.5	14.3	8.5	24.6	13.4	175
Cow dung	54.8	18.6	9.0	19.1	14.4	387

Table 1, above shows the values for volatile matter, fixed carbon, moisture content and ash for sun dried water hyacinth and cow dung used for the study. The values are within the range obtained in other related studies [7]. The gross calorific values for water hyacinth and cow dung were 14.4 and 13.4 MJ/kg respectively. These values are not too different from the range of 17 – 18 MJ/kg obtained for wood and other agricultural residues [9]. The density of unprocessed water hyacinth was 175 kg/m^3 while cow dung gave a higher value of 387 kg/m^3.
The density of uncompressed mixture at different water hyacinth:cow dung mixture ranged from 175 kg/m^3 to 261 kg/m^3 as shown in Table 2. The density of the uncompressed mixture increased with increase in quantity of cow dung added to the water hyacinth. This explains the dual role of cow dung in the briquetting components. It is both a feedstock for the briquette product and a binder. Since cow dung has finer particles than the water hyacinth, it could be explained that the finer the particle, the less the pore spaces and the more the mass of the material per given volume which is good for briquetting. This is in agreement with other related studies [5]-[11].

3.2 . Equilibrium Moisture Content and Density

Table 2: Equilibrium moisture content and density of briquettes

% of water hyacinth to cow dung	Equilibrium Moisture content (wet basis, %)	Compressed density (kg/m^3)	Relaxed density (kg/m^3)	Relaxation ratio
100:0	10.5	1512	884	1.71
90:10	12.9	1764	1069	1.65
80:20	13.7	1851	1157	1.60
70:30	15.1	1970	1296	1.52

From the data in Table 2, the equilibrium moisture content (e.m.c), ranged between 10.5 and 15.1%. There was gradual decrease in e.m.c of the briquettes with increase in the quantity of cow dung in mixture with water hyacinth. The observed e.m.c values fall within the range of values (5.4%- 13.4% wet basis) [6] for coconut husk and waste paper briquettes, and the range of values (7.7-15.1% wet basis) [4] for saw dust and wheat straw briquettes. For good storability and combustibility of briquettes, values within the range of 12-20% wet basis have been recommended [12]. They further noted that an e.m.c in excess of 20% would result in considerable loss of energy needed for water evaporation during combustion at the expense of calorific value of the fuel.
The density of briquettes immediately after compression (compressed density) and density after removal from the press (relaxed density) are parameters used to characterize briquettes. As shown in Table 3, the compressed density of the briquettes ranged between 1512 to 1970 kg/m^3, while the dry (relaxed density) ranged from 884 to 1296 kg/m^3. These values resulted in relaxation ratio of between 1.52 and 1.71. Comparable relaxation ratio of between 1.65 and 1.80 for briquetted hay materials have been observed [13], relaxation ratio of the range of 1.8 to 2.5 for briquetted waste paper and coconut husk have also been reported [6]. The general increase in relaxed density and relaxation ratio with increase in the cow dung in the mixture may be due to the relative higher bulk density of cow dung as already shown in Table 1.

Compared to the density of uncompressed mixtures in Table 1 which ranged from 175 to 261 kg/m^3, the relaxed densities were much higher. Thus the process has been able to achieve increased density which is a valuable factor in briquetting. The values did not differ much from the values of between 1200 and 1400 kg/m^3 reported for agricultural wastes [9].

The higher density and the lower relaxation ratio observed with increasing quantity of cow dung in the mixture may perhaps be due to the plasticity and better bonding nature of cow dung enabling the briquetted materials to form stronger bond, consequently resulting in a denser and more stable product during compaction, than the water hyacinth alone.

3.3 .*Briquette Stability (Linear Expansion)*

It is a well established fact that briquettes compressed in a closed cylinder have a tendency to expand as the pressure is released. The expansion takes place primarily in the direction in which the load is applied, i.e., longitudinal direction. Table 3 shows the increase in length with time of briquettes from the various water hyacinth-cow dung mixtures. The observed linear expansions were generally minimal. Briquettes produced using 100% water hyacinth and 90:10 water hyacinth-cow dung ratio respectively exhibited the largest linear expansion (about 13.6% and 11.8% respectively), while those manufactured at 80:20 and 70:30 and 25:75 ratios exhibited the least expansion (about 10.3 and 9.1% respectively). What this finding seems to suggest is that the cow dung perhaps had some stabilizing effects on the briquettes. It has been noted that the type of material briquetted is one of the factors that have appreciable effects on product expansion [14]. The values are within the reported range for other agricultural wastes such as 6.8 to 20% for rattan waste briquettes heavily dozed with binder material [15] and 3 to 9% for coconut-waste paper briquettes [6].

Table 3: Dimensional stability (minute intervals)

% of water hyacinth to cow dung	0 min	30mins	1440mins	10080mins
		% linear expansion		
100:0	0	13.5	13.6	13.6
90:10	0	11.8	11.8	11.8
80:20	0	10.2	10.3	10.3
70:30	0	8.9	9.1	9.1

The first thirty minutes of the briquettes extrusion was observed to be crucial to its linear expansion characteristics. The highest and most rapid expansion took place within this period. One hour after its extrusion and up to 24 hours, the axial expansion was minimal. This observation is supported by other works [15], [16]-[17], who all concluded that nearly all the expansion of briquettes takes place within 30 minutes of its extrusion. The compressed agricultural residue responds to the basic laws of stress and strain in diverse forms. The material rebounds according to its viscoelastic properties, which may continue for several days naturally with slight increments with a considerable portion of this rebound taking place within a short time after unloading.

3.4. *Durability Rating*

Table 4: Durability rating

% of water hyacinth to cow dung	Durability rating (%)	Standard deviation
100:0	85.3	0.02
90:10	89.8	0.03
80:20	90.5	0.01
70:30	92.7	0.02

Durability is a measure of the ability of a briquette to withstand mechanical handling. The essence of durability is to be able to minimize losses and preserve the quality of the product during handling and storage. Table 4 indicated durability of the briquette produced at different mixing ratio of water hyacinth to cow dung. The durability of the briquettes produced varied in magnitude from 85.3 to 92.7%. Best briquettes were produced at 70:30 mix ratio. Comparable results of the range between 86.5 and 96.5% were obtained for oil palm mush briquettes [18], while range of 96.3 to 98.5% was also observed for coconut husk and waste paper briquettes [9]. Durability is a function of the moisture content and density of the briquettes [19]. While the presence of moisture reduces durability, density tends to enhance it. In this study, durability increased with density of the briquettes, but slightly reduced beyond 13.7% moisture level. Durability is also a function of the bond strength between the constituent parts of the briquettes. The observed increase in durability with increase in cow dung in the mix could also be attributed to the adhesive role the cow dung played in the briquettes. It has been considered that the protein and long cellulose fibre content of combustible wastes were primarily responsible for bonding and stabilization [11] - [20].

3.5 *Water Resistance*

Table 5: Dimensional changes in briquettes after 5-hours immersion in water

% of water hyacinth to cow dung	Initial length (mm)	Final length (mm)	% length expansion (mm)
100:0	36	36.5	1.4
90:10	36	37.0	2.8
80:20	35	36.5	4.3
70:30	37	38.5	4.1

Table 5 shows results of simple immersion test for the briquettes. The post-immersion linear expansion of the briquettes ranged between 1.4 and 4.3%. The briquettes had relatively low water absorptive capacity. Briquettes with only water hyacinth had the least water absorptive capacity. The relatively high resistance of the briquettes to water may be due to the presence of water hyacinth in the briquettes. Water hyacinth is known to have a high cellulose content of the range of 17.1 to 31% [21]. The findings suggest that any exposure of the briquettes to moisture may not have a significant disintegrating effect on them.

3.6. *Combustion Tests*

Table 6: Average fuel gas temperature

% of water hyacinth to cow dung	Flue gas temperature (^{0}C)
100:0	60.5
90:10	64.1
80:20	69.0
70:30	74.5

Data on flue gas temperature of briquettes is presented in Table 6. Briquettes made from only water hyacinth had the lowest flue gas temperature of 60.5 ^{0}C, while the mix ratio of 70:30 water hyacinth/cow dung recorded the highest flue gas temperature of 74.5 ^{0}C. Flue gas temperature increased with increase in content of cow dung in the briquettes. Reported average flue gas temperatures of the range of 51.0 to 70.1 for rice husk/water hyacinth briquettes has been reported [7].

Table 7: Results for water boiling tests

% water hyacinth: cow dung							
100:0		90:10		80:20		70:30	
Time (mins)	Temp. (^{O}C)	Time (mins)	Temp. (^{O}C)	Time (mins)	Temp. (^{O}C)	Time (mins)	Temp. (^{O}C)
0	29.5	0	29.5	0	29.5	0	29.5
5	34.3	5	35.3	5	35.8	5	36.7
10	38.6	10	38.9	10	39.0	10	40.0
15	42.7	15	43.5	15	43.9	15	44.2
20	48.6	20	48.9	20	49.3	20	50.0
25	55.0	25	54.8	25	58.6	25	58.8
30	59.6	30	60.1	30	62.4	30	63.5
35	67.7	35	68.2	35	70.3	35	72.5
40	73.8	40	75.6	40	78.6	40	79.7
45	80.1	45	82.1	45	86.1	45	88.1
50	87.0	50	90.3	50	95.2	50	96.3
55	94.9	55	97.5	54	100.0	51	100.0
59	100.0	57	100.0				

Table 7 shows the temperature versus time recorded for the water boiling tests. It can be observed that water was brought to boiling at 59minutes, 57 minutes, 54 minutes and 51 minutes for 100:0, 90:10, 80:20 and 70:30 water hyacinth–cow dung mixtures ratios respectively. In a related study with only water hyacinth based briquettes about 57minutes was reported for water boiling tests [22].

4. Conclusions

This study indicated that water hyacinth may be used alone or mixed with cow dung as a co-mixture and binder material in briquetting. The results have shown that these biowastes can be compressed and stabilized to density of the order of about 5 times that of uncompressed materials. The briquettes obtained from the water hyacinth: cow dung mixtures were resistant to attrition. For briquette quality control, the physical parameters such as density, moisture content, stability, water resistance and durability were found to be good indicators of quality.

5. Acknowledgement
The authors are grateful to the Petroleum Technology Development Fund, (PTDF), Abuja, Nigeria for providing the research grant for this project

REFERENCES

[1] Economic Commission of Nigeria World solar programme 1996-2005, Projects of the Government of Nigeria: Projects Documents ECN Abuja, 1998.
[2] Abakr, Y.A and A.E. Abasaeed, Experimental evaluation of a conical-screw briquetting machine for the briquetting of carbonized cotton stalks in Sudan Journal of Engineering Science and Technology 1(2): 212-220, 2006
[3] Kirzan, P; Soos L.; Matus M.; Svatek, M and D. Vukelic . Evaluation of measured data from research of parameters impact on final briquettes density Journal of Applied Mathematics 3(3): 70-76, 2010
[4] Wamukonya L. and B. Jenkins . Durability and relaxation of sawdust and wheat – straw briquettes as possible fuels for Kenya. Biomass and Bioenergy 8 (3): 175- 179, 1995.
[5] Bamgboye, A and S. Bolufawi. Physical Characteristics of Briquettes from Guinea corn (sorghum bi-color) Residue. Agricultural Engineering International: the CIGR Ejournal. Manuscript 1364, 2008
[6] Olorunnisola A.O. Production of fuel briquettes from waste paper and coconut husk admixtures Agricultural Engineering International: the CIGR EJournal 4:1-11, 2007
[7] Jamradloedluk, J., Panoemai, C., Tiangkratoke, A and S. Wiriyaumpaiwong. Physical properties and combustion performance of briquettes produced from two pairs of biomass species *ENETT* 49-137: 1-4, 2004
[8] AOAC. Official Methods of Analysis. Association of Official Analytical Chemists. 15th edition, Washington, D.C, USA, 1990
[9] Eriksson, S. and M. Prior. The Briquetting of Agricultural Wastes for Fuel. F.A.O. Rome, Italy, 1990
[10] Waelti, H. and J.B. Dodie. Cubability of Rice Straw as Affected by Various Binder. Transactions of ASAE. 16 (2):380-383 1973.
[11] Chaney, J. Combustion characteristics of biomass briquettes PhD Thesis submitted to the University of Notthingham , 2010
[12] Carre J., P. Lequeux J., Herbert, and L. Lacrosse . Biomass densification. A research projectreport published by the Commission of European Communities, Directorate General for Development, Belgium, 1988
[13] O'Dogherty M.J. A review of the mechanical behaviour of straw when compressed to high densities. Journal of Agricultural Engineering. Research 44:.241-265, 1989.
[14] Bruhn H.D., A. Zimmerman and R.P. Niedermier. Developments in pelleting forage crops.Agricultural Engineering. 204-207, 1959.
[15] Olorunnisola A.O. Briquetting of Rattan Furniture Waste. Journal of Bamboo and Rattan. 3 (2): 139-149, 2004.
[16] Mohsenin, M. N and J, Zaske. Stress Relaxation and Energy Requirements in Compaction of Unconsolidated Materials. Journal of Agricultural Engineering Research. 21 (2): 193–205, 1976.
[17] O'Dogherty, M..J. and J. A. Wheeler. Compaction of straw to high densities in closed cylindrical dies, Journal of Agricultural Engineering Research, 29: 61–72, 1984.
[18] Olaoye, J.O, A.F. Alonge and B.A. Adams. Effects of die diameter mix ratio and compressive force on briquetting of oil palm mush Nigeria Journal of Technological Development 3:27-37, 2003
[19] Husain Z., Z. Zainac and Z. Abdullah Briquetting of palm fibre and shell from theprocessing of palm nuts to palm oil. Biomass and Bioenergy 22:505-509, 2002.
[20] Baker, U.G. Briquetting of Afjin-Elbistein lignite Turkey using different waste materials Fuel Processing Technology 51:137, 1997
[21] Gunnarsson C.C. and C.M.Petersen . Water hyacinths as a resource in agriculture and energy production: A literature review. Waste Management 27: 117-129, 2007
[22] Ighodalo, O.A; K. Zoukumor, C. Egbon, S. Okoh and Odu K. Processing water hyacinth into biomass Briquettes for cooking purposes Journal Of Emerging Trends In Engineering And Applied Sciences (JETEAS) 2 (2): 305-307, 2011