Physical and Chemical Properties of Water Hyacinth Based Composite Briquettes

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ABSTRACT- Biomass is one of the most promising energy sources to mitigate greenhouse gas emission during production and utilization. However, majority of biomass are not suitable to be utilized as fuel without an appropriate process since they are bulky, uneven and have low energy density. The study was conducted to evaluate the physical and chemical properties of water hyacinth composite briquette as an alternative source of energy. Water hyacinth was chopped using a shredder and left for two weeks in a heap to partially decompose. The material was thoroughly mixed manually with dried and crushed charcoal dust and cow dung in the ratios of water hyacinth: charcoal dust: cow dung of 100:0:0 (control), 80:10:10, 70:20:10, 70:10:20, 60:30:10, 60:20:20 and 60:10:30 (by weight). The resulting material was then mixed into soupy slurry in water. Simple prototype briquetting mold was fabricated to facilitate densification of these residues into hollow cylindrical briquette at a pressure of 1Mpa. The experimental results revealed that the calorific values ranged from 16.215 to 21.585 MJ/kg. For quality control, water hyacinth composite briquette gave good indications on physical parameters that were measured. The results showed that resistance to water penetration range from 79.5% to 88%, durability index range from 57.9% to 99.6% with 60:30:10 and 60:20:20 ratios exhibiting poor index of 57.88% and 59.23% respectively probably due to high charcoal dust content which is known to have low bonding. The rest of mixtures gave 80% and above, with water hyacinth (100:0:0 ratio) showing the highest durability index of 99.63% probably because of partial decomposition which increases the binding effect of biomass. Equilibrium moisture content range from 8.5% to 15.2% at 29 0C and 58% relative humidity; water hyacinth alone was having the highest. Water hyacinth composite briquettes possess high material strength as well as high value combustible fuel as can be seen from the experiments that qualify them as an alternative energy source.

Index Terms- Water hyacinth, briquette, durability index, water penetration, charcoal, cow dung

1. INTRODUCTION

1.1 Background information

In the last four decades, researchers have been focusing on alternative fuel resources to meet the ever-increasing energy demand and to avoid dependence on crude oil. Biomass appears to be an attractive feedstock because of its renewability, abundance, and positive environmental impacts resulting in no net release of carbon dioxide and very low sulfur content [5] ,[4], [13], [3]. In many parts of the developing world, Wood-based biomass is facing a threat as a result of deforestation to obtain land for agricultural use. This has resulted in shifting the focus from forest biomass to agricultural and animal residues [9]. In Kenya, the energy sector is largely dominated by petroleum and electricity which are costly and unreliable, with wood fuel providing the basic energy needs of the rural communities, urban poor, and the informal sector. An analysis of the national energy shows heavy dependency on wood fuel and other biomass that account for 68% of the total energy consumption (petroleum 22%, electricity 9%, others account for 1%) [9], [14]. The Energy Act 2006 already recognizes the biomass sector and how biomass regulation should be done setting out a good basis for drafting the biomass plan. It also recognizes the importance of renewable energy and energy efficiency [9].

Water hyacinth, an aquatic weed, spreads rapidly clogging drainage, water intakes, and ditches, shading out other aquatic vegetation and interfering with fishing, shipping and recreational activities [8],[19]. In view of this, the weed has attracted attention of scientists to use it as a potential biomass for production of biofuel because of its high growth yield and availability in large amount throughout the year and all over the world [8],[19].

Lake Victoria, the legendary source of the Nile, second largest fresh water lake was finally losing its capacity to support human life by 1996 due to spread of water hyacinth and this lead to several attempts being made from 1998 to control the weed as part of a larger Lake Victoria Environmental Management Project (LVEMP) [19],[12]. Use of weevils was thought to have brought sigh of relieve by reducing water hyacinth covering about 12 000 ha of shores (Figure 1.1) of Kenya and Uganda by 90% in 1999. This has however had little success as can be noted in a number of documents. [10],[16]

Figure 1.1: Water hyacinth and Stranded boats at Seka beach (Homa Bay)
Source: Author (July, 2015)

Charcoal dust use is expected to reduce the use of firewood and charcoal and therefore pressure on forest resources [20]. This substitution with charcoal briquettes contributes to saving trees, which is important as the country struggles to move from less than 2% of forest cover to the recommended 10% [14]. Saving trees has multiple benefits such as better management of water catchments, mitigating climate change as trees serve as carbon dioxide sinks, and conservation of biodiversity. Briquetting, which is compression and densification of aquatic plants, forest products and by-products, agricultural residues, agro- industrial residues has been long recognized as a viable technology for alternative energy generation and was used in this study.
The objective of the study was therefore to determine the physical and chemical characteristics of composite water hyacinth briquette and was aimed at generating scientific information necessary to promote increased utilization water hyacinth briquette as an alternative domestic source of energy. It is an important way of managing the weed problem and contribution to environment management and will provide part of solution to problems on many parts of Lake Victoria and other water bodies in Kenya.

2. MATERIALS AND METHODS

The test was carried out using water hyacinth harvested from Rare beach of Lake Victoria, Kisumu west Sub-county of Kisumu County. The site is located at longitudes 35^0 4' 5.03" E, latitude of 00^0 59' 54.2"S and altitude of 1135 masl.

Cow dung was obtained from the local zero grazing unit and charcoal dust purchased from a vendor operating in the local area.

2.1 Design and preparation of the briquette

Water hyacinth was chopped using a shredder and left for two weeks in a heap of 3.0m by 0.5m by1.0m to partially decompose. The material was thoroughly mixed manually with dried and crushed charcoal dust and cow dung in the ratios of water hyacinth: charcoal dust: cow dung of 100:0:0 (control), 80:10:10, 70:20:10, 70:10:20, 60:30:10, 60:20:20 and 60:10:30 (by weight). Water hyacinth was given preference as the main feedstock under consideration and therefore cow dung and charcoal ratios were each set at maximum 30% of the total mixtures.

The resulting material was then mixed into soupy slurry in water. The experimental design for this study is single factor (blending ratio) randomized block design with three replications. A total of 252 experiments were conducted with 98 briquette samples per block.

2.2 Compaction of the briquette

Compaction is densification of biomass and affect combustion properties e.g. burning rate, ignition time etc. Compaction was done using metallic cylindrical mold of size 67mm diameter and 40mm tall having holes at the sides and base (for water escape during compaction) with 22.2mm central rod as demonstrated by Chaney [6]. A known quantity (250g) of the briquette mixture was added to the cylindrical mold and compressed manually using a press at a pressure of 1Mpa for wet briquetting to create cylindrical hollow briquette of the mold size which was then removed using ejector (Figure 2.1). Duration of load application of 40 seconds was observed for a briquette during formation .This was done for all samples.

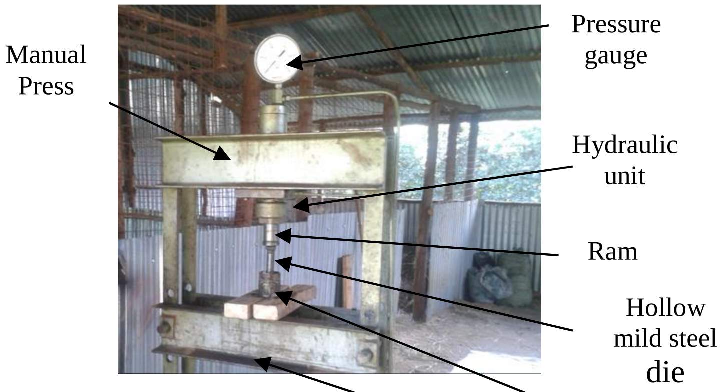

Figure 2.1: Briquetting process using manual Press

Source: Author, 2015

2.3 Physical and Chemical Characteristics of briquette

2.3.1 Chemical characteristics of briquettes

The dried briquette sample from each mixture was crushed using pestle and mortar to ensure homogeneity and sun dried for 7-10 days. Proximate analysis of dry sample weighing 5g was done to determine the percentage moisture content, percentage volatile matter, percentage fixed carbon, percentage ash content and 0.4g for gross calorific value.

2.3.1.1 Percentage Moisture content (PMC)

The moisture content of a solid is defined as the quantity of water per unit mass of the wet solid (wet basis). The moisture content plays an important role in the formation of briquette and subsequently its combustion. High moisture content means a lot of energy needed for water evaporation during combustion at the expense of calorific value of the fuel(<18% recommended), whereas very low moisture content (<10%) need high pressure to compress and therefore expensive and uneconomical. The initial weight of the sample was determined (w_1), and placed in an oven set at 103ºC for 24hours. The sample was removed, cooled in desiccators and reweighed (w_2). Moisture content is then calculated from equation 1. [15],[24]

$$\text{PMC} = \frac{(W_1 - W_2)}{W_1} \text{x} 100 \quad (1)$$

Where;
w_1 = weight of sample before drying, (5g)
w_2= weight of dried sample, (gram)
This was done for 3 replicates for the seven samples

2.3.1.2 Percentage Volatile Matter (PVM)

The resultant masses after the determination of moisture content (2.3.1.1) was placed in a muffle furnace set at a temperature of 400°C. The masses of the samples were removed after 30 minutes, cooled weighed and returned. The experiments were run until no more change in weight of samples is observed. The percentage volatile matter (PVM) is then calculated using equation 2. [15],[24],[17]

$$\text{PVM} = \frac{(b - c)}{a} \text{x } 100 \quad (2)$$

Where,
a = initial weight of sample, (5g).
b = final weight of sample after cooling in desiccators (Heating temperature= 103ºC for 24hours).
c = final weight of sample after cooling (Heating temperature= 400°C).

2.3.1.3 Percentage Ash content (PAC)

The temperature in the furnace was then increased to 800 ^{0}C and the sample left to burn.
The masses of the samples were removed after 30minutes, cooled weighed and returned. The procedure was repeated until no more change in weight was observed. The percentage ash content is then evaluated from the final weights and calculated using equation 3 [15],[24].

$$\text{Ash content, \%} = \frac{\text{weight of ash left}}{\text{weight of sample taken}} \text{ x } 100\% \quad (3)$$

2.3.1.4 Percentage Fixed carbon (PFC)

The percentage fixed carbon (PFC) is computed by subtracting the sum of PVM, PAC and PMC from 100 as shown in equation 4. [15],[24]

$$\text{PFC} = 100 - (\text{PVM} + \text{PAC} + \text{PMC}) \quad (4)$$

2.3.1.5 Calorific value

Analysis employs application of bomb calorimeter according to ASTM-D5468 [10],[15].A known quantity of raw material (0.40g) was added in a crucible and the lid for the bomb closed. Stirrer was started and initial water temperature noted. Current through the crucible was started and fuel sample burnt in the presence of oxygen. Steady state temperature of water (final temperature) was then noted. The Gross calorific value (GCV) of the briquette is calculated using equation 5 [7],[15].

$$\text{Gross calorific value (KJ/Kg)} = \frac{(M_1 + M_2 C_W) \text{x} (T_1 - T_2)}{M_S} \quad (5)$$

Where;
M_1 = heat capacity of calorimeter obtained from standard experiment, KJ/ ^oC
M_2 = Mass of water in copper calorimeter (kg),
T_1 =Initial temperature of water (^{0}C),
T_2 = Final temperature of water (^{0}C),
M_s = Mass of fuel sample taken (kg)
C_w=specific heat capacity of water (KJ/kg ^{0}C)
The tests were done in 3 replicates as above.

2.3.2 Physical characteristics of the Briquettes

2.3.2.1 Equilibrium Moisture Content

The moisture content of a solid is defined as the quantity of water per unit mass of the wet solid (wet basis) and equilibrium moisture content (EMC) is moisture content at which the sample is neither losing nor gaining moisture from the drying air. It depends on temperature and relative humidity of the air. The moisture content plays an important role as explained in (2.3.1.1). Equilibrium moisture content (EMC) of the briquette was determined after 20 days of room drying at 29 ^{o}C room temperature and 58% relative humidity using oven drying method . The initial weight of the sample after drying was measured (W_1), and placed in an oven set at 103ºC for 24hours. The samples were removed and cooled in desiccators then reweighed (w_2). Moisture content of the sample can then be calculated from equation 6 [15],[24].

$$\text{EMC} = \frac{(w_1 - w_2) \text{x} 100}{w_1} \quad (6)$$

Where,
w_1 = weight of sample before drying, (gram)
w_2= weight of dried sample, (gram)

This was done for 3 replicates for all the mixtures.

2.3.2.2 Determination of Bulk density

High density products are desirable in terms of transportation, storage and handling. Bulk density (ρbulk) is the density of a material when packed or stacked in bulk; it depends on the solid density, geometry, size, surface properties, and the method of measurement. It was determined 20 days after removal from the press and dried.

A stereo metric method was used to determine briquette bulk density. This was chosen over displacement methods in order to ensure the briquettes remain dry. The mass of briquette was determined using laboratory electronic balance (Bosch, PE 625) with accuracy of 0.01g. The diameter was measured at three points; top, center, and bottom of the sample. Length was also measured at three points. These measurements were done using vernier calipers. The density for each briquette is calculated and the mean density for the 5 briquettes per batch determined and recorded.

$$\text{Density} = \text{mass of sample, g/Volume of sample, m}^3 \quad (7)$$

2.3.2.3 Compressed density

Compressed density of briquette was determined immediately after removal from the press. High compressed density briquette give low burning rate and therefore good quality. The mass of briquette was determined using laboratory electronic balance (Bosch, PE 625) with accuracy of 0.01g .The diameter was measured at three points; top, center, and bottom of the sample. Length was also measured at three points. These measurements were done using vernier calipers. It is calculated as the ratio of measured weight over calculated volume using equation 8 [24].

$$\text{Compressed density} = \frac{108000\text{xM}}{(l_1+l_2+l_3)\text{x}\,\pi\,\text{x}\,((d_1+d_2+d_3)^2-(3d)^2)}\ \text{g/cm}^3$$
(8)

Where, d_1 , d_2 and d_3 are diameters of briquettes at the three points respectively and d is the internal diameter measured in millimeters. l_1 , l_2 and l_3 are lengths of briquettes at three points measured in millimeters and M is the mass of briquette in grammes. This was done for 3 replicates for all the mixtures.

2.3.2.4 Relaxed density

Relaxed density of briquette was determined 20 days after removal from the press and dried. The procedure is like that for determining compressed density. [24]

$$\text{Relaxed density} = \frac{108000\text{xM}}{(l_1+l_2+l_3)\text{x}\,\pi\,\text{x}\,((d_1+d_2+d_3)^2-(3d)^2)}\ \text{g/cm}^3$$
(9)

Where, d_1 , d_2 and d_3 are diameters of briquettes at the three points respectively and d is the internal diameter measured in millimeters. l_1 , l_2 and l_3 are lengths of briquettes at three points measured in millimeters and M is the mass of briquette in grammes.

Relaxed density and compressed density are parameters used to characterize briquettes. High relaxed density implies that the briquette has good dimensional stability and therefore stable as a product giving low relaxation ratio (the product is good if the ratio is approaching one).It is calculated using equation 10.

$$\text{Relaxation ratio} = \text{Compressed density/Relaxed density} \quad (10)$$

2.3.2.5 Durability

Durability is the measure of the ability of briquette to withstand mechanical handling. This test is done to minimize losses and preserve quality of the product during handling and storage. It is a function of moisture content and density. High moisture content reduces durability whereas high density enhances it. Briquettes durability index was measured according to ASTM D440-86(2002) of drop shatter developed for coal [6], [8]. The test was conducted after two weeks of briquettes samples formation. A test sample of five briquettes of known weight (W_1) was placed in a plastic polythene bag. The bag was dropped from a height of 2m onto concrete floor three times. After the dropping, the briquettes and fractions was placed on top of a 35mm square mesh screen and sieved. The experiment was replicated three times. The durability rating for each type of briquette is expressed as the ratio of weight of material retained on the screen (W_2) to weight of briquettes before the dropping. The handling durability of the briquettes is computed using equation 11[6], [8],[22].

$$\text{durability index, \%} = \frac{W_2}{W_1} \quad (11)$$

Durability of 80-90% is considered good and anything above 90% is very good. [12]

2.3.2.6 Water resistance

Water resistance is the measure of water absorptive capacity of sample when immersed in water. High absorption of water may lead to significant disintegration. Water resistance of dry briquettes was determined by immersing one sample per batch each in a glass container filled with water at room temperature for 2 minutes .Weight of briquette was measured before and after immersion in water using laboratory electronic weighing balance. This was replicated 3 times. The percent water gain is calculated and recorded by using equation 16 and then percentage resistance to water penetration is calculated using equation 12 [8],[15].

$$\text{Weight gain by briquette , \%} = \frac{W_2-W_1}{W_1}\ \text{x}\ 100 \quad (12)$$

Where;
W_1 = Initial weight of briquette, g
W_2 = Weight of wet briquette, g

$$\text{Resistance to water penetration, \%} = 100 - \%\ \text{water gain}$$
(13)

3 RESULTS AND DISCUSSIONS

3.1 Physical and Chemical Characteristics of briquette

3.1.1 Chemical characteristics of briquettes

The dried briquette sample from each mixture was crushed using pestle and mortar to ensure homogeneity and sun dried for 7-10 days. Proximate analysis of dry sample weighing 5g was done to determine the percentage moisture content, percentage volatile matter, percentage fixed carbon, percentage ash content and 0.4g for gross calorific value and results shown below (Table 3.1).

3.1.1.1 Proximate analysis, calorific values of sun-dried briquette

Table 3.1: Proximate and calorific values of sun-dried briquette against blending ratio

Blending Ratio	calorific value , MJ/Kg	Ash content %	Moisture content %	Volatile matter %	Fixed carbon %
60:30:10	20.835	19.43	6.39	32.6	41.58

Table 3.2:Continued

60:20:20	19.16	21.27	7.25	35.5	35.98
60:10:30	17.585	17.62	6.95	40.00	35.43
70:20:10	21.585	21.25	6.41	38.84	33.50
70:10:20	18.42	22.47	9.30	38.00	30.23
80:10:10	18.99	23.2	7.58	35.12	34.11
100:00:00	16.215	17.17	10.34	41.7	30.79

Calorific values are ranging from 16.215 - 21.585 MJ/kg (Table 3.1) which is within the range for charcoal and other agricultural wastes (15 - 30MJ/kg). Apart from water hyacinth (100:00:00), the other calorific values are fulfilling the minimum requirement of calorific value for making commercial briquette (>17.50 MJ/Kg) as given by [24]. Water hyacinth alone (100:00:00) has given a very good calorific value compared to what was obtained by[12] of 13.4MJ/Kg. This may have been possible due to increased density after partial decomposition.
It was expected that mixture of 60:30:10 having 30% charcoal would have high calorific value but instead 70:20:10 are giving higher calorific value probably due to its bonding i.e this observation could be adduced to porosity exhibited between inter and intra–particles which enable easy infiltration of oxygen and out flow of combustion briquettes .

3.1.2 Physical characteristics of the Briquettes

These properties relate to fact that the briquettes should not crumble and disintegrate when handled, stored and transported, and is mainly a function of the quality of the densification process for a given raw material. The results are discussed below;

3.1.2.1 Equilibrium Moisture Content (%)

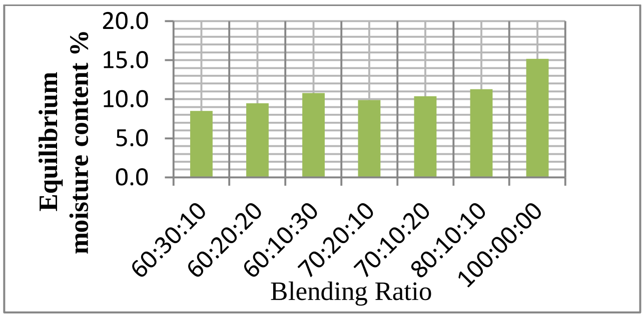

Figure 3.1: Equilibrium moisture content against blending ratios

Mean equilibrium moisture content at temperature of 29 ^{o}C and 58% Relative humidity range from 8.5% to15.2% (Figure 3.1). For good storability and combustibility of briquettes, equilibrium moisture content of <18% recommended by [15] and therefore the briquettes produced fall within range .There is a general increase in equilibrium moisture content with increase in cow dung and water hyacinth, the latter (100:00:00) showing the highest equilibrium moisture content of 15.2%. It can also be concluded from the results that equilibrium moisture content decreases with increase in charcoal dust. The lowest equilibrium moisture content was given by the mixture of 60:30:10 having 30% charcoal dust. Antonio concluded that environmental conditions and particle size range strongly influence the moisture at equilibrium and the uptake rates [24]. The smaller the feedstock particles, the higher the moisture content at equilibrium and the moisture uptake rate. This probably explains why materials with high water hyacinth and cow dung ratios have high equilibrium moisture contents. The two materials soften more reducing their particle sizes when water is added to them compared to charcoal dust.

3.1.2.2 Bulk density (g/cm^3)

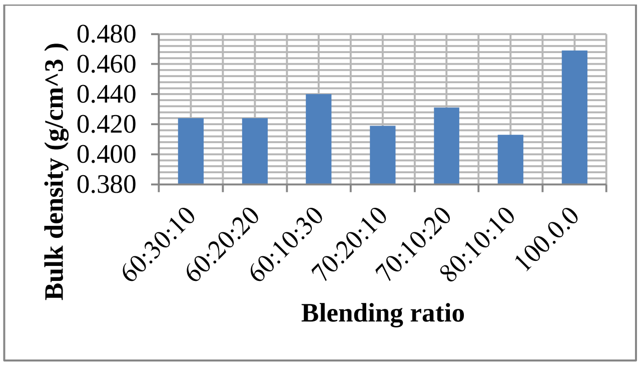

Figure 3.2: Bulk density against blending ratios

Mean bulk density range from 0.413 g/cm^3 to 0.469 g/cm^3. The densities are low due low compression pressure of 1Mpa.It is seen that within the same water hyacinth ratio, bulk density reduces with increased charcoal dust. However, Water hyacinth alone has surprisingly the highest bulk density. This is due to high shrinkage with corresponding heavy loss in weight probably as a result of partial decomposition (Figure 3.2).
Anova table (Appendix A1) shows that at $\propto= 0.05$, blending ratio (P-value,0.0076<$\propto= 0.05$) and blocking (P-value,0.2282 >$\propto= 0.05$) have significant effect on bulk density, otherwise means of blending ratios apart from that of water hyacinth alone are not significantly different using Duncan's Multiple Range Test (Appendix B1)

3.1.2.3 Compressed density (g/cm^3)

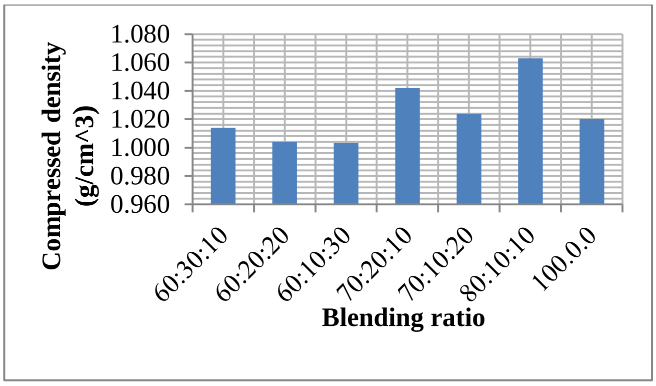

Figure 3.3: Compressed density against blending ratios

High compressed density briquette give low burning rate and therefore good quality. The experiment shows that, compressed density range from 1.003 g/cm^3 to 1.063 g/cm^3

(Figure 3.3). It is difficult to attach any sequence in relation to proportion of water hyacinth. However, it can be seen that at 60% and 70% water hyacinth, compressed density increases with increase in charcoal dust.

3.1.2.4 Relaxed density (g/cm^3)

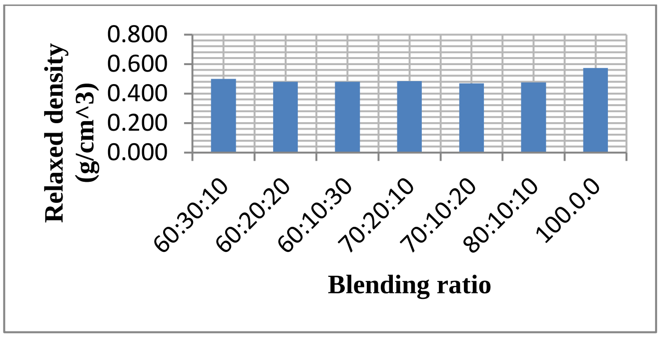

Figure 3.4: Relaxed density against blending ratios

Relaxed density and compressed density are parameters used to characterize briquettes. High relaxed density implies that the briquette has good dimensional stability and therefore stable. Mean relaxed densities are ranging from 0.468g/cm3 - 0.574g/cm3 .The densities are low due low compression pressure of 1Mpa.

Anova table (Appendix A2) shows that at ∝= 0.05, blending ratio (P-value,0.0013<∝= 0.05) and blocking (P-value,0.1933 >∝= 0.05) have significant effect on relaxed density otherwise means of blending ratios 60:30:10,60:20:20,60:10:30,70:20:10, 70:10:20 and 80:10:10 are not significantly different using Duncan's Multiple Range Test(Appendix B2)

3.1.2.5 Relaxation ratio

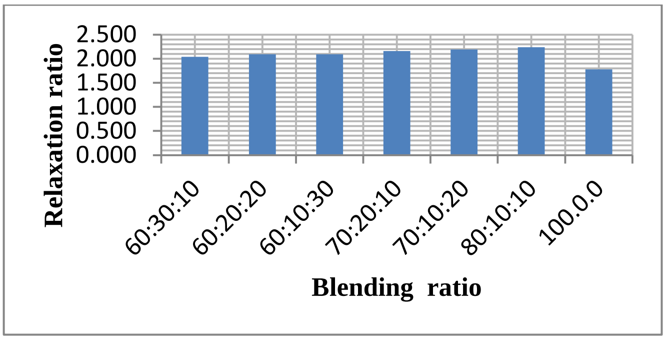

Figure 3.5: Relaxation ratio against blending ratios

Blending ratio 60:30:10 has high relaxed density and corresponding low relaxation ratio (Figure 3.4 & 3.5). There is a general trend in increments of relaxation ratio as we increase water hyacinth and cow dung (Figure 3.5). However, Water hyacinth alone has surprisingly the highest relaxed density and lowest relaxation ratio. This is due to high shrinkage (reduction in volume) with corresponding heavy loss in weight probably as a result of partial decomposition (Figure 3.4 & 3.5).

The other mixtures lost weight by nearly 50% with less than 10% loss in volume. This scenario also explains the results of bulk density.

Anova table (Appendix A3) shows that at ∝= 0.05, blending ratio (P-value, 0.0054<∝= 0.05) have significant effect on relaxation ratio and blocking (P-value, 0.0454≈ ∝= 0.05) have no significant effect on relaxation ratio otherwise means of blending ratios 60:30:10,60:20:20,60:10:30,70:20:10, 70:10:20 and 80:10:10 are not significantly different using Duncan's Multiple Range Test (Appendix B3)

3.1.2.6 Durability (%)

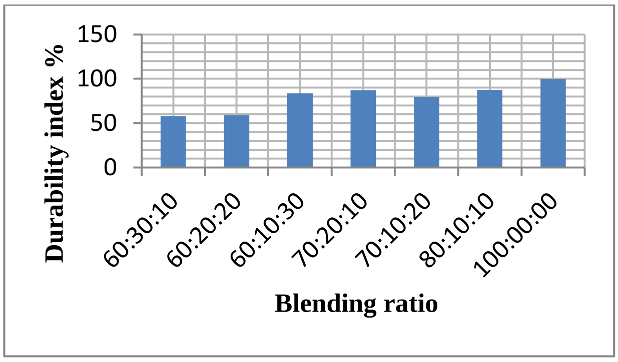

Figure 3.6: Durability index against blending ratios

Durability is a function of bond strength between constituent parts of briquette. Durability of 80-90% is considered good and anything above 90% is very good. Mean durability index for this experiment is ranging from 57.88% to 99.6% (Figure 3.6). The ratios 60:30:10 and 60:20:20 are exhibiting poor index probably due to high charcoal dust content which has low bonding as confirmed by Eriksson and Prior]10]. The rest of mixtures have 80% and above, with water hyacinth (100:0:0 ratio) showing the highest durability index of 99.63% probably because of partial decomposition which increases the binding effect of biomass.

Anova table (Appendix A4) shows that at ∝= 0.05, blending ratio (P-value 0.0001 <∝= 0.05) and blocking (P-value,0.3433>∝= 0.05) have significant effect on durability otherwise means of blending ratios 60:10:30, 70:20:10, 70:10:20 and 80:10:10 are not significantly different using Duncan's Multiple Range Test (Appendix B4)

3.2.1.7 Water resistance (%)

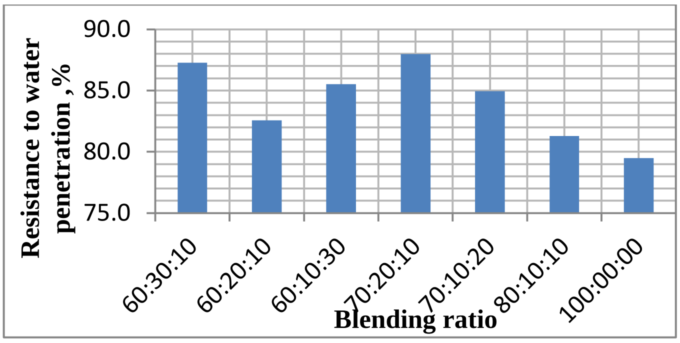

Figure 3.7: % Resistance to water penetration against blending ratios.

Mean percentage Resistance to water penetration for 2minutes range from 79.49% to 87.98% and therefore the briquettes have very low absorptive capacity (Figure 3.7). The relatively high resistance of the briquettes to water penetration may be due to the presence of water hyacinth in the briquettes. Water hyacinth is known to have a high cellulose content of range of 17.1 to 31% according to Frank [12]. However, mixtures 60:30:10 and 70:20:10 have highest resistance to water penetration whereas water hyacinth alone shows the least resistance most likely because of partial decomposition which softens the cellulose.

Anova table (Appendix A5) shows that at $\propto = 0.05$, blending ratio has no significant effect on water resistance (P-values $0.0922 > \propto = 0.05$) and blocking has significant effect on water resistance (P-values $0.7092 > \propto = 0.05$), otherwise means of blending ratios 60:30:10,60:10:30, 70:20:10 and 70:10:20 are not significantly different using Duncan's Multiple Range Test (Appendix B5).

4 CONCLUSION AND RECOMMENDATIONS

For quality control, the water hyacinth composite briquette gave good indications on physical parameters that were measured e.g. durability index, densities, relaxation ratio. The water hyacinth briquettes possess high material strength (durability index) as well as high value combustible fuel as can be seen from the experiment.

Based on the findings of this study and the conclusions made above ;the production of water hyacinth composite briquettes and its utilization could be advocated since its usage as solid biofuel, will alleviate the menace caused by this aquatic plant.

Utilization of water hyacinth as a composite briquette could also enhance: rural economic development, farm income, and market diversification, reduction in agricultural surplus, reduced negative environmental impact and creation of employment opportunities in the area of production, harvesting and utilization.

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APPENDIX

Appendix A: Anova tables

Appendix A1: Bulk density, g/cm^3

Source	DF	SS	MS	F-Value	Pr>F
Treatment	6	79.27525714	13.21254286	34.46	<.0001
Block	2	0.31202857	0.15601429	0.41	0.6746
Error	12	0.00243524	0.00020294		

Coeff Var 3.302684

Appendix A2: Relaxed density, g/cm^3

Source	DF	SS	MS	F-Value	Pr>F
Treatment	6	0.02416724	0.00402787	7.87	0.0013
Block	2	0.00193457	0.00096729	1.89	0.1933
Error	12	0.00613876	0.00051156		

Coeff Var 4.57982

Appendix A3: Relaxation ratio

Source	DF	SS	MS	F-Value	Pr>F
Treatment	6	0.43138429	0.07189738	5.66	0.0054
Block	2	0.10286752	0.05143376	4.05	0.0454
Error	12	0.15250114	0.01270843		

Coeff Var 5.40149

Appendix A4: Durability index

Source	DF	SS	MS	F-Value	Pr>F
Treatment	6	0.42746362	0.07124394	16.3	<.0001
Block	2	0.01023038	0.00511519	1.1	0.3433
Error	12	0.05244695	0.00437058		

Coeff Var 8.340748

Appendix A5: water resistance, %

Source	DF	SS	MS	F-Value	Pr>F
Treatment	6	347.0045905	57.8340984	2.41	0.0922
Block	2	17.0059714	8.5029857	0.35	0.7092
Error	12	288.4806952	24.0400579		

Coeff Var 5.868522

Appendix B: SAS results

Appendix B1: SAS results for bulk density (g/cm^3)

No.	Mixture	No. of trials	Mean Bulk density	Duncan grouping
1	100:00:00	3	0.46900	A
2	60:30:10	3	0.44000	B
3	70:20:10	3	0.43033	B
4	60:20:20	3	0.42433	B
5	60:10:30	3	0.42433	B
6	70:10:20	3	0.41867	B
7	80:10:10	3	0.41267	B

NB: Means with the same letter are not significantly different.

Appendix B2: SAS results for relaxed density (g/cm^3)

No.	Mixture	No. of trials	Mean relaxed density	Duncan grouping
1	100:00:00	3	0.57433	A
2	60:30:10	3	0.49800	B
3	70:20:10	3	0.48267	B
4	60:20:20	3	0.48000	B
5	60:10:30	3	0.47900	B
6	80:10:10	3	0.47500	B
7	70:10:20	3	0.46800	B

NB: Means with the same letter are not significantly different.

Appendix B3: SAS results for relaxation ratio

No.	Mixture	No. of trials	Mean Relaxation ratio	Duncan grouping
1	80:10:10	3	2.25667	A
2	70:10:20	3	2.18900	A
3	70:20:10	3	2.16167	A
4	60:10:30	3	2.09600	A
5	60:20:20	3	2.09333	A
6	60:30:10	3	2.03600	A
7	100:00:00	3	1.77667	B

NB: Means with the same letter are not significantly different

Appendix B4: SAS result for durability index (%)

No.	Mixture	No. of trials	Mean Durability index %	Duncan grouping
1	100:00:00	3	99.600	A
2	80:10:10	3	87.600	B
3	70:20:10	3	87.233	B
4	60:10:30	3	83.633	B
5	70:10:20	3	79.667	B
6	60:20:10	3	59.233	C
7	60:30:10	3	57.867	C

NB: Means with the same letter are not significantly different

Appendix B5: SAS result for water resistance (%)

No.	Mixture	No. of trials	Mean water resistance,%	Duncan grouping
1	70:20:10	3	88.090	A
2	60:30:10	3	87.203	A
3	60:10:30	3	85.693	A
4	70:10:20	3	84.927	A
5	60:20:20	3	82.510	BA
6	80:10:10	3	81.130	BA
7	100:00:00	3	75.287	B

NB: Means with the same letter are not significantly different