



Converting Water Hyacinth to Briquettes: A Beach Community Based Approach

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Abstract

Attempts by the government of Kenya to control the noxious water hyacinth via various intervention efforts have had limited success only for the weed to resurge. The proliferation of water hyacinth in Lake Victoria – Kenya has decimated the livelihoods of the locals and reduced the water quality, among other negatives. Meanwhile, the indigenous trees and bushes have been felled for firewood leading to environmental degradation. This study explored water hyacinth briquettes as alternative to the local wood fuels through a pilot briquette production process by appropriate levels of technology mediation. The commonly used biomasses, reasons for community's preference of one species to another were also sought.

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The survey of 152 randomly sampled respondents from Beach Management Units (BMUs) in Kisumu, Kendu Bay and Homa Bay beaches established commonly used firewood tree species whose samples were collected and tested for the calorific value, ash content, volatile matter, fixed carbon and moisture content. These were compared via paired samples t –test with those of prepared samples of water hyacinth briquettes. The study indicated that the calorific value of water hyacinth briquettes was statistically different from those of local plant fuels at $T = 7.01$ and $df = 7$, and at 95% confidence level. The decision by the community to use any biomass as fuel depends on its abundance and not on cost or amount of heat generated, thus the choice of hyacinth as alternative energy could be based on its abundance and not its calorific value.

Keywords: Water hyacinth; Briquette; Calorific value; Carbonization; Semi decomposition

1. Introduction

Water hyacinth (*Eichhornia Crassipes*), is a free floating aquatic weed that originated in the Amazon basin in the South Americas and the world's most difficult waterweed to control [46]. It is a fast growing perennial aquatic macrophyte [7]. It is a member of pickerelweed family (*Pontederiaceae*) and its name *Eichhornia* was derived from well known 19th century Prussian politician J.A.F. Eichhorn [38]. This tropical plant spread throughout the world in late 19th and early 20th century [2]. Today, it is well known for its reproduction potential [45] and as a plant that can double its population in only twelve days [37].

In its original habitat the weed's proliferation is kept under check by its natural predators, but in the absence of the latter, an abundance of space, agreeable temperature conditions, and an abundance of nutrients cause the weed to spread so prolifically that it covers water surfaces with a floating matt like cover [18]. Due to its attractive blue, lilac to purplish flowers and round to oval leaves, the water hyacinth was initially spread by botanists and gardener as an ornamental crop species in many countries more than a century ago and was a prized species [40,44]. It is best suited to tropical and sub-tropical climates [27] and has spread very fast in countries of Latin America, the Caribbean, Africa, Southeast Asia and the Pacific [47].

Water hyacinth seeds have a long dormancy period of up to 15 - 20 years, sprouting rapidly when conditions are ideal and spreading quickly. Therefore whilst mitigation methods may have appeared to have been successful they have flared up again, reappearing just as quickly as they vanished [15].

Three main control mechanisms for preventing the spread of water hyacinth exist each having its benefits and drawbacks. These are; biological control, chemical control and physical control [26, 2, 24, 21].

Currently, several useful applications for the plant have been found. These range from: making paper, fiber boards for a variety of end use, basket making, charcoal briquetting, stock feed [39], pretreatment for polluted water [12], biogas production, fish feed [27] to compost manure [39]. A water hyacinth

infestation is never eradicated, instead, it is a situation that must be continually managed [14,44], therefore control by utilization and specifically by energy briquetting, remains the only sustainable option of dealing with the weed as this takes up great quantity of the weed at a time. The rising prices of traditional energy sources and the global warming problem have led to a large effort to promote renewable energy. This has intensified the search for alternatives to fossil fuel in the face of modernization and industrialization. Exacerbated by ballooning energy costs, water hyacinth in this regard holds a strong promise in the 21st century bio-fuel industry [8].

1.1 Objectives

The following objectives were investigated:

To find out the common firewood biomass species

To develop a technology for converting water hyacinth to energy briquettes

To compare the properties of common firewood biomasses with those of water hyacinth samples

To propose a beach community strategy for controlling water hyacinth through a sustainable briquetting technology

2.0 Literature Review

This section traces the origins of water hyacinth, geographic distribution, growth and reproduction, potential as renewable energy and the properties of biomass fuel.

2.1 Origin, Distribution, Growth and reproduction of water hyacinth

Water hyacinth became a problem in the USA after it was distributed to participants in the 1884 cotton exhibition [18] from where it got widely distributed in southern states like Alabama, California, Florida, Louisiana, Texas and others [7]. In the same period the weed spread throughout the tropics of the continents around the world, north and south as far as 40° north and south latitude [48]. In its original habitat the weed's proliferation was kept under check by its natural predators, but in the absence of its enemies, an abundance of space, agreeable temperature conditions, and an abundance of nutrients the weed spread so prolifically covering water surfaces with thick floating matt like cover [9]. Around the 1880s it was spotted in Egypt [30] invading many of African rivers and lakes [28], with catastrophic socioeconomic and ecological consequences [48]. The weed is suspected to have entered the East Africa region and Lake Victoria from Rwanda through River Kagera [35], from where it has spread in the whole of the Nile Basin. The plant was introduced by colonists in Rwanda to beautify their holdings and then advanced by natural means to Lake Victoria and the Nile basin, where it became a concern in 1988 [4].

Water Hyacinth great reproduction potential and growth is primarily dependant on: ability of the plant to use solar energy, nutrient composition of water, and environmental factors [5]. Under normal conditions loosely packed water hyacinth can cover the water surface at relatively low plant density (10 kg/m² wet weight) and it can reach maximum density of 50 kg/m² wet weight before growth ceases. Author in [2,48,27] who studied water hyacinth during flowering which lasts about 15 days, obtained similar results about its phenology and generative reproduction.

2.2. Water Hyacinth as Renewable Energy

The word renewable from renew means “to give new strength”. Renewable Energy thus mean: energy that can be given new strength. Renewable Energies derivable from the natural movements and environment such as: sunshine, wind, the heat of the earth, the movement of seas and rivers and the growth/movement of plants and animals. A renewable energy system transforms incoming solar energy and its primary alternate forms (wind and river flow), usually without pollution-causing combustion into readily usable form of energy such as electricity, [20]. Water hyacinth as a weed that quickly utilize solar and its high nutrients uptake from its surroundings perfectly fit a description of a plant that can generate renewable energy directly. With value addition such as briquetting through carbonization or semi decomposition higher energy yielding briquettes can be obtained [31].

The decreasing availability of fuel wood, coupled with the ever rising prices of kerosene and cooking gas in Kenya, draw attention to the need to reconsider alternative sources of energy for domestic and cottage level industrial use in the country. Such energy sources should be renewable and should be accessible to the poor thus; a transition to a sustainable energy system is urgently needed in the developing countries such as Kenya [29]. An energy source that meets such sustainability requirements is fuel briquette. It is produced at low cost and made conveniently accessible to firewood and charcoal for domestic cooking and agro-industrial operations, thereby reducing the high demand for both. Besides, briquettes have advantages over fuel wood in terms of greater heat intensity, cleanliness, convenience in use, and relatively smaller space requirement for storage [3]. Briquetting can be done with or without binder. Doing it without the binder is more convenient but it requires sophisticated and costly presses and drying equipments which makes such processes unsuitable in a developing country. As observed [3], for briquetting industry to be successful in the less industrialized countries, the equipment should consist of locally designed simple, low-cost machines.ial operations, thereby reducing the high demand for both.

Wood fuel is the largest form of energy consumed in the Kenya, accounting for about 68% of the national total. Petroleum is the next most important accounting for 22% followed by electricity 9%. Only 2% of Kenya’s land area is covered by forest, which produce about 45% of the biomass energy resources including wood wastes [49]. The balance is derived from farmlands in the form of woody biomass as well as crop and animal residues [43]. Water hyacinth can be a solution for this renewable energy promotion scheme as well as an alternative for reduction of green house gases emissions, by being an alternative to the fast declining wood fuels, that are useful in carbon sequestration and

reduction of GHGs. This is because the water hyacinth is very rich in proteins that are easily biodegradable. Its protein content varies from 6 – 17% on the dry matter basis, low lignin of about 10% [8]; [23], therefore cellulose and semi-cellulose are more easily converted to fermentable sugar resulting in utilization of biomass for biofuel industry [40,11,13,32,31].

Energy remains essential for development, but exploitation of energy sources needs to be carried out with sustainability in mind. The biomass briquettes derived from water hyacinth can have remarkable contribution to the energy-mix more so with the rural communities who largely depend on wood fuel. Studies have established that most of the energy consumed in Kenya is in form of charcoal, wood fuel and crop residues and given the rapid urbanization, there will be an accelerated demand for charcoal hence wood removal that causes complete destruction of whole trees.

There exists linkage between provision of affordable energy and poverty alleviation and developing pro-poor programs in priority areas such as; opportunity (income and capabilities), empowerment and security. The governments in sub-Saharan Africa believe that increasing access to improved energy services through rural electrification caused poverty reduction [36].

2.3 Fuel Properties of Biomasses

Human beings from the hunter-gatherer society to the modern society have always applied heat to improve the nutritional quality of food and warm houses. No human populations in the recorded history are known to have lived without regular access to cooked food [50,25]. The basic and most accessible source of fuel for fire used in cooking are the various plant species. Each species of wood has unique properties regarding amount of heat dissociated upon complete combustion. This is called calorific value and it is the quantity of heat evolved by complete combustion of the unit mass of the substance in an enclosure of constant volume and is affected by the moisture content of a given wood species among other factors [34].

The main components of wood cells are cellulose, hemicelluloses and lignin, forming some 99 % of the wood material [6]. Lignin which is rich in carbon and hydrogen is the main heat producing elements. Thus its calorific value is higher than that of cellulose and hemicelluloses (carbohydrates). Wood and bark also contain so-called extractives, such as terpenes, fats and phenols. The amount of wood extractives is relatively small compared to the amount of extractives from bark and foliage. [6]. The interest in this research was solid fuel production in the form of briquettes. Water hyacinth is very promising in terms of its use as alternative source of solid energy for heating. The main parameters in determining briquette quality are its moisture and ash content, volatiles materials among others [42].

The *calorific value* (CV) is the most important fuel property that determines the energy content of a fuel and is the property of biomass fuel [42]. The CV of a fuel is impacted on by a number of other factors such as the moisture content which if low increases combustion and invariably increasing the heat value [42]. CV is the amount of energy created when one kilogram of absolutely dry wood is

burned and all water created in burning process is condensed also called the Higher Heating Value (HHV) or combustion heat, is normally given per kilogram of solid wood. It is in the range 18.5-21.0 MJ/kg for wood. Most forestry departments normally measure the amount of stem wood as solid cubic meters (m^3) with the denser species naturally have higher heating value per m^3 of solid stem wood [10].

The *moisture content* (MC) has big effect on the net calorific value reached at the burning process. It is expressed as weight % of the wet base (as received). Vaporising water requires energy from the burning process (0.7 kWh or 2.6 MJ per a kilogram of water), thus reducing the net heating value of the fuel. The moisture content of wood fuels are in the range 20 to 65 % and is influenced among other things by: climatic conditions, time of the year, tree species, part of the stem, storage phase [10]. Moisture content of 15% and below can be reached in the tropical heats around Lake Victoria without extra energy input for drying. Higher moisture content in the range of 70-80 %, make the wood to no longer support the burning process. Moisture content over 20% leads to remarkable loss of energy required for water evaporation during combustion at the expense of the calorific value of the fuel. Such a fuel may not also be stable for long storage.

The *ash content* (AC) of a bio fuel means the amount of solid wastes after complete burning process of the fuel. It can be expressed as weight % of the dry base. High ash content of the fuel generally reduces its heating value. The ash content of wood biomasses ranges from 0.08 to 2.3 % [11].

The *volatile matter* (VM), consists of the combustibles of solid fuels classified into two groups: *volatile matters* and components combusting as *solid carbon*. The share of volatile matters of wood is typically high, 80% of the energy originating in the combustion of volatile matters [22]. The bark, crown and stumps of the tree have typically somewhat higher effective heating values than the stem wood [16].

3.0 Methodology

3.1 Research Design

There were two sources of data: primary and secondary sources of data. Survey and direct observations were the primary sources while the analysis of existing literature was the only secondary source. The data was collected through survey of BMU members that employed questionnaires and laboratory tests of collected wood and water hyacinth derived fuel samples. SPSS Version 16.0 for windows was used to analyze the data broken into two thematic areas, namely; descriptive that detailed respondents' characteristics and inferential that tested the hypotheses. The results of analysis were displayed in tables, figures and numerical values of the hypotheses test.

3.2 Target Population

The study targeted the Beach Management Unit Members (BMUs) as they were the people most impacted on water hyacinth infestation. The study region was split into three parts Kisumu zone,

Kendu Bay zone and Homa Bay zone due to the migratory nature of water hyacinth between the three regions as per prevailing winds.

3.3 Sample Design

The fishing industry on the Kenyan side of Lake Victoria employs about 50 000 people of which 5206 were from the study region [14]. Being a finite population [51], Bayesian sample formula was used to arrive at the sample size of ~119. This was proportionately distributed across the zones and questionnaires randomly administered to the BMU members. The data collected included 183 filled in questionnaires of which 152 were found to be usable. This implied the response rate was good and the increase in number allowed as it lead to increased representativeness.

3.4 Reliability Test

The content Reliability of survey data was established through test-retest method where the same test was repeated after some time under the same conditions. This involved 10% of the respondents, translating to 15 respondents distributed proportionately across the three zones. The interim consistency reliability of measures was checked for the 29 items used and found Cronbach's alpha at .762 which meant that the reliability of measures were acceptable as it was above the threshold of .70 [17].

3.5 Study Area

The study was done in two counties around Lake Victoria that suffer chronic water hyacinth covers. These were two zones of Kendu and Homa Bay in Homa Bay County, and Kisumu county n Kenya (Figure 1)



Figure 1: Map of the Study Area

3.6 Pilot Production: Hyacinth Briquette Making Process

The production process for converting water hyacinth to briquettes begins with harvesting, then chopping and lastly drying all done manually. This then followed by two separate processes; carbonization and semi decomposition.

Harvesting of the weed (manual)

Sorting (whole plant, roots , stalks :manual),

Chopping (manual)

Drying

Carbonization or semi-decomposition

Mix with binder

Feed into briquette machine when mixture is consistent (squeeze test)

Dry in the sun

Determine heating value of the briquettes

The top level flow diagram of water hyacinth briquetting process shows the two types of processing employed, to yield a product mixed with binder then molded in the press by extrusion (Figure 2).

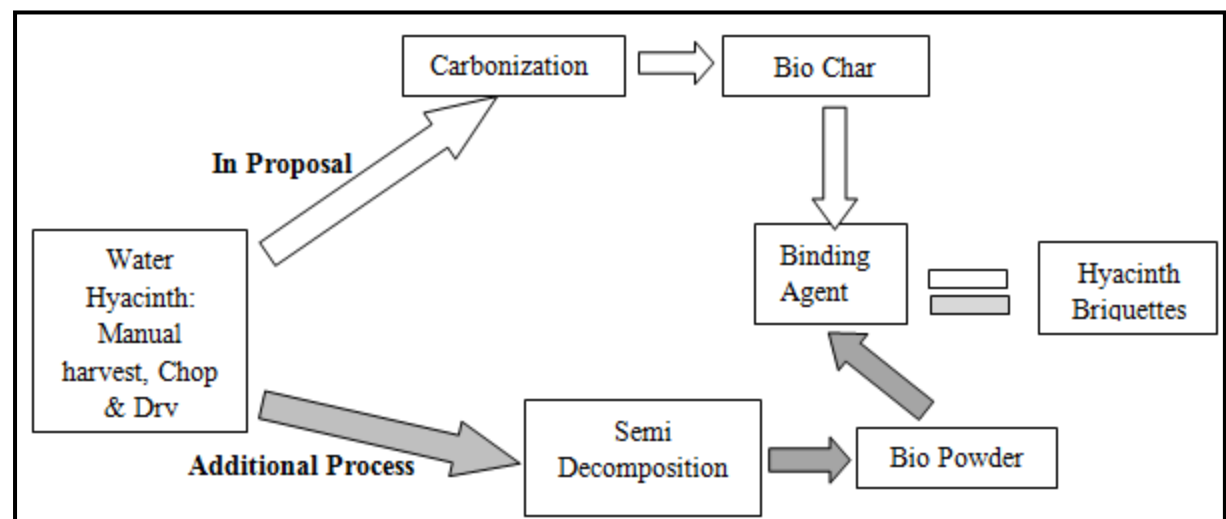


Figure 2: Top Level Flow Diagram

Carbonization is the process of burning the dry hyacinth parts in a modified metallic drum under low oxygen. For the carbonization process the following materials need to be available: water hyacinth materials dry to crispy level, a straight log of wood (diameter = 4 inches and length = 4 feet), lighting materials that are sufficiently dry (dry grasses, dry papyrus heads etc), 4 stones, box of matches, and carbonization drum with some modifications.

The carbonization process delivers dark charcoal pieces which when mixed with a binding agent can be molded through a manually operated extrusion system to get the briquettes. The processing of the weed for carbonization was done in three different ways: water hyacinth carbonized wholly (stalk + roots), stalk only or roots separately (Figure 4).

Semi_Decomposition The material for this process was stalk only as the roots if included take too long to decompose. The stalk dried for 4 days should be checked for being crispy (crunchy/brittle/crusty) and brown in color.

Materials required: dried hyacinth materials, polythene decomposing bags and effective microorganism solution (EM₁ solution). This speeds up the activity of microorganisms on the material. Once set up the process takes 14 days but the bags must be turned after 7 days to allow microbes act from the opposite direction. The dimensions of the bags are in (Figure 3)

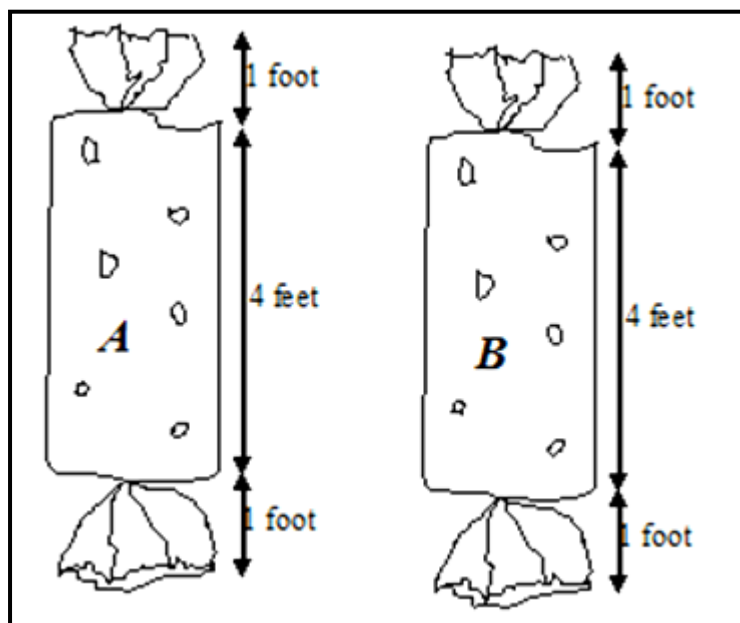


Figure 3: Dimensions of Semi decomposition Bags

A white stick (Plate 1) is inserted in each bag to gauge temperature of the decomposing material. The measure of temperature is an indication of microbe activity. This is done by pulling out the stick and inspecting for colour change and temperature by touch. A thermometer would be preferred here. High temperature is lowered by adding water at room temperature.



Plate 1: Semi Decomposition Process

A rotting smell will be observed from the bags and the white stick when withdrawn is found to be warm on touch after 24 hours. After 14 days the process is stopped and materials aired out to dry taking just 3 days to dry up. This is then ground using a manual grinder and the resulting powder mixed with binder then compressed manually by hand or machine to yield briquettes (Figure 4).

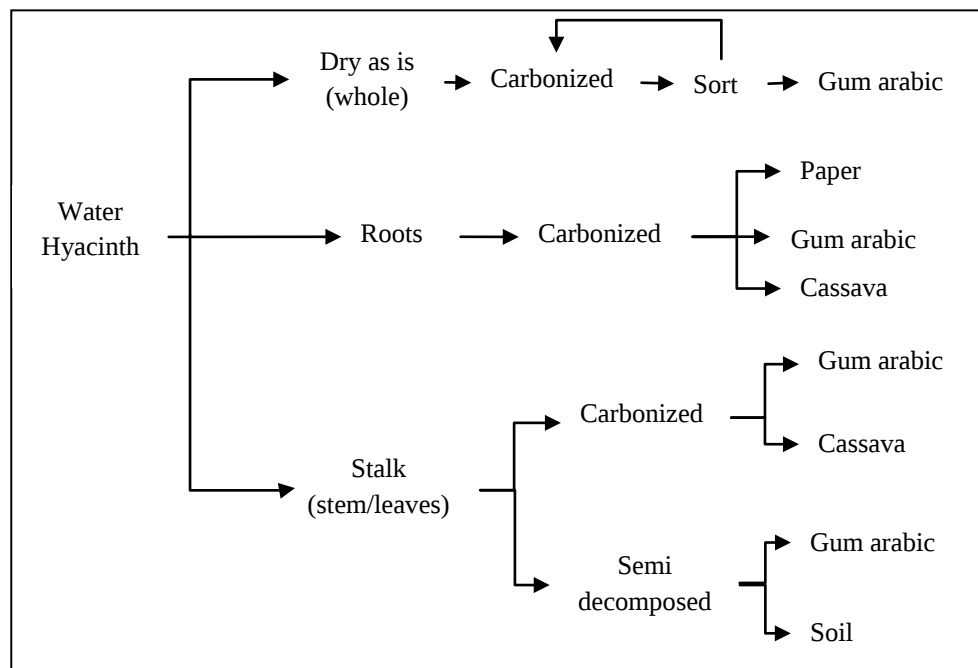


Figure 4: Production: Hyacinth, Part, Process and Binder

Binders: Four different binders were used in the study with various parts of hyacinth and process. These were; clay, waste paper, gum arabic and cassava porridge.

Samples: Eight different hyacinth samples and eight commonly used wood fuel samples were collected and tested for four different parameters: Calorific value, Moisture content, Fixed Carbon and Ash content

4.0 Results

Two sets of findings are presented:

- a) Baseline survey and analysis of common firewood biomasses; reasons for preference of plant fuel by community members and
- b) Laboratory tests and analysis of various briquettes samples in terms of; calorific value, moisture content, volatile matter, ash content, and fixed carbon.

4.1 Common and Preferred Bio Fuels

It was revealed from a crosstab of biomass type and zone, that *Lantana camara* was the most commonly used plant as wood fuel with 57(37.50) of respondents identifying it as the most common. *Euphorbia* was at 27 (17.76%), *thevetia peruviana* 22(14.47%), *papyrus* 17 (11.18%), *albizia carriara* 13(8.55%), *makhimia alutea* 9 (5.92%) while *cassia siamea* recorded 7(4.61%) (Table 1).

Table 1: Biomass Type*Zone Crosstab

Biomass Type	Zone			Percent	
	Kisumu	Kendu Bay	Homa Bay	Total	%
<i>Lantana Camara</i>	28	7	22	57	37.50
<i>Euphorbia</i>	15	4	8	27	17.76
<i>Thevetia Peruviana</i>	5	4	13	22	14.47
<i>Papyrus</i>	8	2	7	17	11.18
<i>Albizia carriara</i>	4	2	7	13	8.55
<i>Makhimia Alutea</i>	3	1	5	9	5.92
<i>Casia Siamea</i>	3	1	3	7	4.61
Total	66	21	65	152	100.00

The question of the most preferred plant fuels in their area was to aid the identification of the species for purposes of comparison with calorific values of hyacinth derived briquette samples. Since this was

open, a frequency table revealed the order of preference. The (Table 2) shows some of the most preferred plant fuels in three zones displayed in order of preference.

Table 2: Preferred Plant Fuels

Tree Species	Kisumu	Kendu Bay	Homa Bay	Total	Percent (%)
<i>Lantana camara</i>	27	10	22	59	38.82
<i>Euphobia</i>	15	5	12	32	21.05
<i>Thevetia peruviana</i>	10	2	12	24	15.79
<i>Papyrus</i>	7	1	7	15	9.87
<i>Albizia carriaria</i>	3	1	5	9	5.92
<i>Makhimia Alutea</i>	3	1	4	8	5.26
<i>Casia Siamea</i>	1	1	3	5	3.29
Total	66	21	65	152	100.00

4.2 Reason for Preference of Plant Fuel by Community Members

The respondents' reason for preferring a specific biomass was sought to reveal variables to compare with water hyacinth derived samples. These were in terms of cost, availability, quality of heat and any other reason for preference (Table 3).

Table 3: Reason for Preferring a Plant Fuel

Zone/	reason for preference of plant fuel species				
Reason	Kisumu	Kendu Bay	Homa Bay	Total	Percent
<i>Abundant</i>	51	17	47	115	75.66
<i>Cheap</i>	6	2	13	21	13.82
<i>More heat</i>	9	0	5	14	9.21
<i>Others</i>	0	2	0	2	1.32
Total	66	21	65	152	100.00

The main reason for preference of a particular plant fuel species is its abundance at 115 (75.66%) as opposed to the expected emphasis on cost which stood at 21(13.82%) while quantity of heat produced by a particular plant fuel which stood at 14(9.21%) (Table 3). Any other reason for choice of a plant fuel was not recorded except two respondents (1.32%) in Kendu Bay. The abundance was the main reason across all the zones for choice of a particular biomass for use as source of energy for heating.

4.3 Analysis of Laboratory Test Results

The results of the sample tests were done using a bomb calorimeter [1], at the Kenya Industrial and Research Development Institute (KIRDI).

4.3.1 Calorific Value of Water Hyacinth visa versus Wood Based Fuels

The paired samples t – test used indicated that the mean calorific value was 7.9025Kcal/g and 3.7013Kcal/g for wood based fuels and hyacinth derived samples respectively, and these are different. At 95% confidence level, $p = .000 < .05$ (Table 4) thus there is no sufficient evidence to accept the null hypothesis and so the alternative hypothesis is accepted, that is there is significant difference between mean calorific value of wood fuel (7.9025) and that of water hyacinth samples (3.7013). Among the hyacinth samples, semi decomposed hyacinth stem with gum arabic binder had the greatest cv of 4.23 Kcal/g while semi decomposed hyacinth stem with soil (clay) binder had the least 3.21Kcal/g. This gives an indication that the best quality hyacinth briquette comes from the semi decomposed stalk with gum arabic binder.

A scrutiny of the production process reveal the semi decomposition briquettes as one that takes more time, requires greater attention and other materials thus leading to higher production cost. The carbonized whole hyacinth with gum arabic binder at 3.22Kcal/g is lower and it is therefore imperative that best results for hyacinth briquettes in terms of heat released on combustion is obtained from the two parts separately carbonized with respective binders. That is carbonized roots with gum arabic binder at 4.17Kcal/g and carbonized hyacinth stem with cassava binder at 4.16Kcal/g. Other than CV, other parameters obtained from the bomb calorimeter were: moisture content, volatile matter, ash content and fixed carbon.

Table 4: Paired samples Test

	Paired Differences							
				95% Confidence Interval of the Difference		T	df	Sig.(2- tailed)
	Mean	SD	S.E.M	Lower	Upper			
w – h Samples	4.20	1.69	.599	2.78	5.61905	7.01	7	.000

Wood based samples while h – water hyacinth based samples

Briquetting can as well be done after grinding the dry hyacinth without a binder material and using sophisticated machines to press the material into briquettes, but this can be costly and out of reach of most community sections as reported by [19]; [3]. The process where readily available binders are used

becomes cost effective with only the need of extrusion machine made from local materials as fronted in this study.

The w_7 and w_8 were derived from papyrus stalk and crown respectively, yet their cv were different though the same binder (gum arabic) was used, with that of the former being 7.37 Kcal/g and the latter 3.77 Kcal/g. this is not in agreement with the [16] assertion that crowns of plants have higher cv than the stem part. In general, though water hyacinth briquettes have lower cv compared to their wood samples, [3] found that they produce greater heat intensity, cleaner, more convenient to use and take up smaller space for storage.

4.3.2 Moisture Content = mc

Both the wood based and hyacinth derived samples largely had the same moisture content when they were presented to the tests ranging from 3.81% to 5.55 %. It was observed that;

$$\text{Average } mc(h_1 - h_8) > \text{average } mc(w_1 - w_8)$$

$mc(h_{7\&8})$ are relatively much higher than $mc(h_{1-6})$ perhaps due to semi-decomposition as opposed to the carbonization process

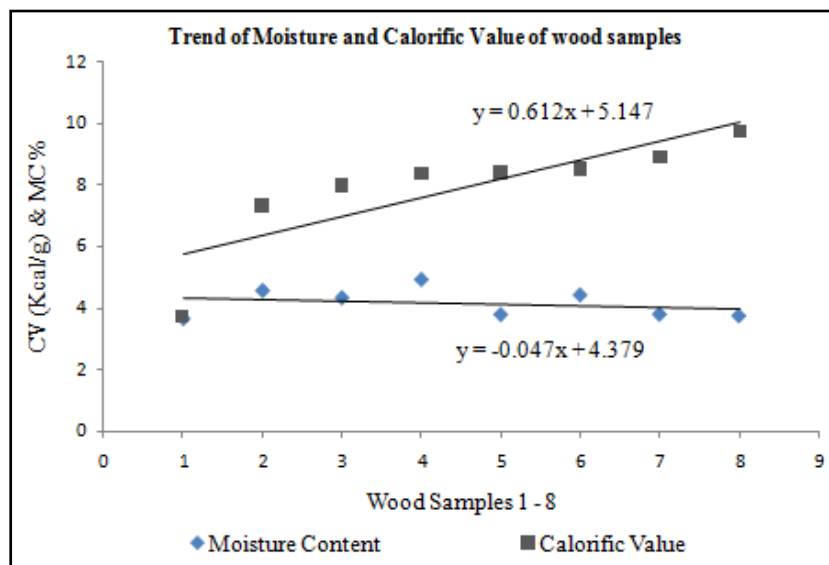


Figure 5: Moisture and Calorific Value Trend Line for Wood

There is an inverse relation between the calorific value and the moisture content (Figure 5). The negative gradient for the moisture content and the positive gradient for the calorific value trend lines indicated that while moisture content increase, the calorific value decline and vice versa. [34] argued that the calorific value is influenced by the moisture content. This study has shown that influence of moisture content on calorific value is an inverse one and that moisture content levels of below 20% can

be achieved through open natural drying around Lake Victoria without extra energy requirement in concurrence with [10].

There was only one sample with moisture content of above 20%. Such *mc* lead to remarkable energy loss in vaporizing the moisture present and are also unstable for longer storage [42]. This shows that most of the sample made from water hyacinth were of good quality because their *mc* were in the range 3.92% - 5.26% except for samples from semi decomposition process (h_7 & h_8) that were 18.44% and 20.57% respectively.

4.3.3 Volatile Matter = *vm*

The *vm* for hyacinth derived samples was found to approximately equal to that of the wood based samples in disagreement with the findings of [22], that woody biomasses possess greater volatile materials compared to other biomasses. Most of the samples were carbonized before testing for the volatile matter which could be the reason for similar combustible materials. The semi decomposed water hyacinth stalk with gum arabic binder (h_7) had the highest *vm* of 49.58% possibly due to the semi decomposition process as opposed to carbonization. Semi decomposed water hyacinth stalk (h_8) had the least *vm* of 25.28% yet it was also not carbonized but semi decomposed. This difference could have resulted from the difference in the binders used which was in this case clay.

4.3.4 Ash Content = *ac*

The ash content *ac* of samples h_{1-8} were remarkably higher ranging from 29.59% to 74.66% compared to wood based samples w_{1-8} that ranged from 3.45% to 51.61% with that from papyrus at 51.61% singling out as an out lier. This negates the findings by [10], that ash content of woody biomasses is in the range .08% to 2.3%. Hyacinth derived samples had higher *ac* perhaps due to the binders that acted as fillers thus contributing to higher *ac* and possibly due to their low carbon fixing ability [33]. In general the heat content of w_{1-8} , is higher than those of h_{1-8} samples and the ash content of hyacinth briquettes higher than those of w_{1-8} . Therefore, it can be presumed that the higher the heat content, the lower is the ash content and vice versa.

4.3.5 Fixed Carbon = *fc*

The hyacinth samples had very low fixed carbons compared to their wood based counterparts. These values for the hyacinth briquettes ranged from 2.35% to 6.91% while those of the wood samples varied from 13.66% for papyrus to 70.32%, which were all above 50.00%. The other wood plant derivatives ($w_{1 \text{ to } 6}$) have high *fc* values > 57.53% if we discount the papyrus derived samples which are relatively low i.e. *fc* (w_7 & 8) = 3.66% and 1.66% respectively. The samples that had high *fc* also had high *cv*, thus, fixed carbon is a measure of calorific value.

4.3.6 The *Jiko* (charcoal stove) test

Trial of the two types of samples burnt in a *jiko* in order to boil water for *uji*, yielded the following results (Table 5);

Table 5: Hyacinth Briquette Samples h_2 and h_6

Sample No.	Percentages%					Kcal/g		
	MC	VM	AC	FC	CV	Base Plant	Process	Binder
h_2	4.92	25.32	62.85	6.91	3.22	Whole Hyacinth	Carbonized	Gum arabic
h_6	4.22	19.14	74.32	2.32	4.17	Hyacinth Roots	Carbonized	Gum arabic

The h_6 sample was difficult to light, needed to be fanned continuously and would not sustain burning; it also turned a dark orange color as it was being fanned. The latter was ash which would not burn but when shaken rapidly fell to the bottom of the *jiko* as ash. Presumably indicating that the roots contain much mud/and or sand.

The h_2 sample on the other hand lit quite fast and produced a sustained heat which was sufficient to boil water and prepare *uji* to perfection. It appears that the whole water hyacinth plant carbonized briquette which although having a lower calorific value and higher volatile matter produces a lower ash residue than the h_6 sample which is relatively higher in fixed carbon.

The sheer abundance of the water hyacinth, due to its methods of reproduction and longer seed dormancy periods of up to 20 years make it difficult to eradicate [41]. However, this makes its use very sustainable as an alternative to wood fuel as well as to make it fit the description of a source of renewable energy.



Plate 2: *Jiko* Test Burn (Incandescence)

5. Conclusion

The purpose of this study was to assess the potential of water hyacinth as an alternative to wood fuel through energy briquettes technology by community involvement in Kisumu, Kendu Bay and Homa Bay regions. The comparison of calorific value of water hyacinth dry matter with those of local wood fuels showed existence of significant difference between them, however the decision to use any particular biomass as fuel dependent merely on its abundance. Therefore, even though water hyacinth has about half calorific value of local plant fuels, it is so abundant and this should encourage its use as an alternative fuel. On average the Water hyacinth derived briquettes compared to those derived from other wood plant material have:

greater moisture content (*mc*) 8.28% versus 4.48%

similar amounts of volatile matter (*vm*) 26.03% versus 25.19%

much greater ash content (*ac*) 62.92% versus 21.99% except in the case of w_7 and w_8 (51.61% and 71.2% respectively) both papyrus derived

significantly much less fixed carbon (*fc*) 2.78% ($h_8 = 0.09\%$) versus 48.35%

much lower calorific value (*cv*) 3.70 K cal/g versus 7.90 K cal/g

6. Recommendations

Based on the findings of this study and the conclusions made, we recommend the following:

Treat the abundance of water hyacinth and its relatively significant heat content as an opportunity to sensitize the local communities that it is indeed an alternative biomass with economic and environmental advantages.

Take advantage of the increasing unemployed youth as a potential that can be trained to tackle the weed whenever its effects get profound.

Demonstrate to the fishermen that when WH makes fishing untenable, the weed can be turned into a source of income through the briquette making process.

Generate monitoring systems to track specific infested areas and their seasonal movement. These efforts need to be integrated and cut across the communities that are faced with this water hyacinth challenge.

Educate the communities on the possible opportunities for controlling water hyacinth that are within their scope of knowledge and resources to handle.

Collaborate with The Ministry of Energy and Industrialization and KIRDI to make heavy duty water hyacinth briquetting presses to address the issue of briquette energy density.

Educate the community living around the lake on the nature of water hyacinth so that even when it appears to be under control, vigilance and preparedness for its resurgence are necessary.

Promote water hyacinth to briquette production as a cottage industry in beach communities where water hyacinth prevails seasonally to provide a substitute for charcoal and fossil fuel for domestic cooking and heating of water thereby :

saving expenditure on similar *household* items which could be made available for other basic necessities,

Conserving eventually vital national forex spent in the importation of fossil fuels and

Conserving Kenya's environment by decreasing the dependence on wood based fuels as the uptake of water hyacinth briquetting technology by more community members scales up.

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