THE INTERNATIONAL JOURNAL OF SCIENCE & TECHNOLEDGE

Efficacy of Sewage Sludge Briquettes Mixed with Sugarcane Bagasse as a Fuel Alternative

Ann Muthoni Njue
Assistant Civil Engineer, Department of Hydraulic & Environmental,
China State Construction Engineering Corporation (CSCEC), Nairobi, Kenya
Mercy Wang'eri Hinga
Assistant Civil Engineer, Department of Water & Sanitation Engineering,
Mangat I.B Patel (MIBP) LIMITED, Nairobi, Kenya

Abstract:
This research aimed to study the efficacy of briquettes derived from sewage sludge mixed with bagasse as a fuel alternative. Sludge is a significant waste from the process of wastewater treatment, whose disposal has become a significant challenge. Another biomass waste facing a disposal challenge is bagasse, which is a waste product produced in the manufacture of sugar. Sustainable solutions to the problems of improper sludge and bagasse disposal, adverse deforestation for charcoal and wood provision and low fuel in the country should be addressed adequately to reduce the adverse effects on the environment. Therefore, characterization and determination of efficacy of sludge derived fuel briquettes will be vital. Sewage sludge was mixed with sugarcane bagasse in the ratios of 1:0, 1:1, 2:1, 3:1, and 3:2. The briquettes were then prepared using a briquetting machine into standard sizes of 3cm both in diameter and in height. Fuel briquettes properties as calorific value, ash content, moisture content, fixed carbon, volatile matter, and shattering index were then determined. From the research, the ratio of 1:1 gave the highest calorific value of 2965.68 cal/g. It had an ash content of 11.846%, moisture content of 4.702%, fixed carbon of 53.024%, volatile matter of 30.788%, and a shattering index of 18.966%. Therefore, more research and development is required to improve the quality and performance of the briquettes. The addition of sugarcane bagasse to sewage sludge improved the calorific value of the sludge hence making them an efficient source of fuel. Therefore, the briquettes can be used as a fuel alternative, which will be a long-term solution to sludge disposal problem, environmental pollution, and high levels of deforestation in Kenya.

Keywords: *Briquette, sludge, bagasse, calorific value, feedstock*

1. Introduction

1.1. Problem Statement

Sustainable solutions to the problems of improper sewage sludge and bagasse disposal, adverse deforestation for charcoal and wood provision and low fuel in the country should be addressed adequately to reduce the adverse effects posed to the environment and community.

Sludge is a significant waste from the process of wastewater treatment, whose disposal has become a significant challenge in the developing countries more so, in Kenya. In reality, themost substantial by-product of wastewater treatment is sludge. It is a composite mixture of industrial materials, primary inorganic grains and biological fragments designating the residue solid by-products from wastewater treatment. Management of sludge is carried out in stages which include; sludge production, treatment, and disposal. The quantity and quality of sludge produced in the treatment process make up the production; treatment comprises numerous methods used to convert sludge into a form that is allowable for disposal, and disposal embraces alternatives for final disposal or utilization of sludge.

Although sludge represents only 1% to 2% of treated wastewater volume, its treatment and disposal are highly complex and costly with expenses ranging from 20% to 60% of the wastewater treatment total operating cost. Consequently, it is disregarded in the design of wastewater treatment plant, causing it to be undertaken without prior planning by plant operators. There are various ways which have been used to discard the sludge waste including; application as a fertilizer in the farms, disposal in landfills and incineration. However, this has not been as effective as required since the methods of disposal have profound effects on the environment. (Sperling, 2007)

The most common methods of disposal of sewage, which include dumping in landfills and use as a fertilizer in farms have become a major threat to human health and the environment. They may have delayed or linear effects on the environment. The treatment before dumping determines the leaching capability of the sludge hence defining its impact to the environment. It may contain detrimental constituents such as pathogens, organic compounds and superfluous nitrogen that have adverse impacts to the environment.

Use of sludge in agricultural land is limited becausemajor investments in storage facilities have to be made since sludge can only be used on farmlands occasionally in a year. Additionally, most farmers in the country are not enlightened on sludge use as a fertilizer and if they are, do not trust its use. Also, there is precise legislative control since the sludge has to meet specific quality standards before its considered safe for application in farms. In Kenya, these standards are difficult to meet since most treatment plants are old and outdated compromising their efficiency.

Incineration, which is a popular thermal technique of disposal, has also turned out to be a cause of concern due to its discharges into the soil, water, and air as well as its expensive nature. Where co-incineration is used, the efficiency and capacity of the treatment depend on the permeation of the furnace by other solid waste materials, and the ratio of solid waste mass to sludge mass. The ashes produced also have to be disposed of in landfills, making it not entirelyuseful as the process is not self-dependent. There have been attempts of producing fuel briquettes however the quality of briquettes produced does not meet the standard calorific value of 5000cal/g. This has left the problem of sludge waste disposal without an efficient and reliable solution. (N. Supatata, 2013)

Another biomass waste which is of interest is bagasse, which is a waste product produced in the manufacture of sugar after the crushing of the sugarcane. The bagasse production is very high as statistics show that approximately 3 tonnes of wet bagasse are reproduced for every 10 tonnes of sugarcane crushed. It is estimated that currently about 1.6 million tonnes of bagasse is produced annually in Kenya. Out of this quantity, only 25% is economically utilized for the generation of heat for internal use in factory boilers. Every year, numerous tonnes of this waste remain underutilized as they are heaped occupying vast tracts of lands or burned. However, this is faced witha significant challenge due to itshigh-water content.(AZEUS, 2012)

The sugar industry faces the challenge of appropriate and cost-effective disposal of enormous amounts of bagasse. The most practiced disposal method is used as a fuel in cisterns running at sugar pulverizers. The mills require installation and proper maintenance of stack scrubbers to wash the emission since it is not mainly a clean fuel.

Additionally, the high levels of moisture (45-60%) hinder utilization of bagasse as a boiler fuel. For efficient operation due to its bulkiness, special furnaces have to be constructed for efficient operation. Bagasse has a high cellulose content making it a potential renewable source of biomass. (Nelson L. Nemewa, 1998)

Alternative ways of disposing bagasse have been implemented such as paper manufacture and use as a fuel however they have not been effective. This is because it contains high moisture content usually 40-50 percent that is unfavorable to its usage as fuel. Bagasse is a homogenous material, whose burning capability is more predictable, because the biomass is composed of fibers with more or less similar characteristics, like composition and size. Therefore, production of better performing briquettes by use of bagasse will be of great help in solving the environmental challenge at hand. (Silveira, 2005)

On the other hand, the issue of unclean and insufficient fuel in Kenya is notably dominant; where some 80percent of the population rely on charcoal or wood for fuel. This has resulted in deforestation from fuel-cutting activities and enormous health risks from cookstove pollution. This is because high energy sources which are cleaner are costly and are used by households with higher levels of income compared to those with low levels of income who use the low-cost fuel with undesirable effects.

About 2.5 billion people use biomass as a fuel source according to the International Energy Agency. According to research by Kenya Forest Service, charcoal provides about 82 percent of the energy in urban families. Thus far its usage is resulting insignificant deforestation- research done in 2013 found out that the demand for charcoal was roughly 16.3 million m^3 with a supply of only 7.3 million m^3. Shockingly, it was found out that the air pollution from inadequately burning solid fuels such as charcoal could lead to the death of about 4.3 million people a year. A solution to these problems could be switching to cleaner cooking stoves. This can be doneby changing fuel by the production of sludge fuel briquettes rather than swapping stoves, which seems like an efficient way. (Silver, 2016)

When a thermal application is considered as a disposal method, an essential characteristic of bagasse and sewage sludge is their thermal or energy content or heating value. This is a significant property considered when evaluating the potential of sewage sludge and bagasse as a source of fuel. Therefore, the manufacture of fuel briquettes from these biomass wastes will be a sustainable solution to the environmental pollution, public health problems, and inadequacy of fuel.

Briquette manufacture is a means to transform biomass waste and sewage sludge through simple and affordable technology that is inexpensive and appropriate to be managed by small societies, particularly in developing countries. It encompasses assemblage of inflammable materials that are not usable and compacting them into a dense fuel product of any suitability. They are commonly made from material and binder.

Combustible materials include char, low-grade biomass, and bagasse. A binding agent is necessary to increase the cohesion of flammable materials. If not well bound, the briquette will crumble when removed from the mould. Examples of flammable materials include animal manure, treated and dewatered sludge while binding agents include starch, wax, clay molasses and cement.

The sewage sludge has some characteristics including low heat value, high moisture content, low ash content, density, and viscosity. On the other hand, bagasse has a lower ash content, has low density and tend to float and fly inconveniencing storage, and it can be made into high heat value products. If these materials are variegated in appropriate proportions, it may solve their glitches and compensate their shortcomings with each other. To produce good briquettes, three main physiochemical properties have to be put under consideration including; flow characteristics, moisture content, and ash content. Moisture content should be minimal. This is because high moisture content requires excessive energy for drying and will cause problems in firing. Moreover, this can affect the quality of combustion.

Biomass should contain an ash content less than 4% since high ash content is mainly made up of huge alkaline earth metals. These components are characterized by a low fusion temperature that causes an increase in the slagging potential. Also, flow characterization should be high. Particles with low flow properties lead to breaking. Highly granular homogeneous materials can flow smoothly in conveyor, shelters and storage silos that are appropriate for briquetting in cases of large-scale production. (N. Supatata, 2013)

Many benefits are accrued to the creation of high-quality briquettes from sludge and bagasse. There will be a noticeable reduction in the amount of biomass waste contaminating the environment, hence reducing various health risks and enhancing the quality of the surroundings. Additionally, the setting will be saved by preventing deforestation from fuel-cutting activities. Although sludge has previously been used as a fertilizer, the sludge and bagasse briquettes represent a new brand of the table-to-toilet-to-kitchen cycle that could lessen the health impacts of cooking while also being economically desirable.

Kenya vision 2030 recognizes the need for efficient and sustainable waste management systems to be established as the country develops into a newly industrialized state. In the next decades, there will be an adverse impact on thewastewater production and the potential for both decentralized treatment and use. This is because most substantial rates of urbanization will occur in the smaller urban centers (between 500,000 and 1 million inhabitants). This will significantly impact wastewater production and environmental pollution. (Waste Water: untapped Resource, 2017) .

The study will examine the efficacy of the fuel briquettes produced from sewage sludge variegated with bagasse. There have been various challenges experienced in the disposal of excess sludge and bagasse causing environmental pollution. Over the years, there has been a rapid increase in sludge and bagasse waste hence there is a need for discovering innovative alternatives for their disposal. Furthermore, severe shortages of fuelwood have been realized which can be attributed to the combination of an exploding population and high rates of deforestation in the country.

Briquetting is undergoing resurgence, due to the following factors: the economics of using fuel briquettes as an energy source has changed significantly because of recent development in briquette processing and binding.

Use of biomass waste to produce fuel briquettes is an economical option for fuelling household energy needs in the country, whose 80 percent of the population rely on charcoal and wood fuel. Due to the improved processing, production of well-performing briquettes can be achieved. Waste-derived briquettes burn and produce very little ash with less than 5% with little to no odour. No known environmental problems with briquetting waste or burning waste-derived briquettes have been reported.

The abundance and availability of sewage sludge waste makes it suitable, potentially cost-effective and reliable raw material for producing fuel briquettes. Producing fuel briquettes is an option for treatment and recycling of this type of waste, next to biogas production. When the moisture content of sludge based fuel briquettes is less than 14%, it has a calorific value of (17-25 Mega-Joules MJ/Kg) that is equivalent to that of fuel coal, which makes it very suitable for use as a source of fuel briquette (Asamoa, 2016).

Owing to bagasse as a fibrous biomass material, it strongly intertwines and adheres to other material used in briquetting. As a result, they do not separate from each other during combustion. Further, bagasse is a combustible material used in boilers of sugar mills to generate steam and for heat purposes. (NPCS Board of Consultants & Engineers, 2015).

Applying the fundamental principles of management, some goals/objectives shouldbe achieved. To protect the health of the population, especially low middle and low-income groups. Secondly, to protect the environment by controlling water, air or soil pollution hence ensuring the sustainability of the ecosystem. Lastly, provision of efficient use and conservation of valuable materials and resources will be realized.

Therefore, characterization and determining efficacy of sludge derived fuel briquettes will be vital in providing an alternative source of energy, while solving the environmental challenge of biomass disposal.

1.2. Objectives

To investigate the efficacy of briquettes derived from sewage sludge mixed with bagasse as an alternative source of fuel.

To determine the correlation between the calorific value of the briquettes and the different ratios of sewage sludge and bagasse.

To evaluate the mechanical and physical properties of the briquettes in comparison to the features of the wood charcoal standard.

2. Methodology

2.1. Materials

- Sewage sludge
- Sugarcane bagasse
- Saw dust as a carbonizer
- Molasses as a binder

Various tasks were carried out to come up with reliable data, which included the following;

- Production of the five briquette samples by mixing the materials in the stipulated ratios.
- Calorific value test was carried out on the briquettes produced in comparison to charcoal briquettes, to determine the best performing briquette.

- Ash content, fixed carbon, volatile matter, moisture content tests were carried out to determine the physical and mechanical properties of the briquettes in comparison to the features of the wood charcoal standard.

2.2. Procedure for Briquetting

2.2.1. Adjustment of the Moisture Content

The moisture content of bagasse and the sewage sludge was adjusted through sun drying to obtain the recommended moisture content. Bagasse was spread on a clean, dry surface and left to dry for three days under the sun. Moisture content influences the quality of the briquette produced by forming a solid bridge between particles. Low moisture may cause roughness and thus inhibit the effective bonding of materials. This will decrease the tensile strength of the briquettes. Since the sludge will be obtained from the sludge drying beds, there is no need for moisture adjustment.

High moisture content, on the other hand, may increase the cost of drying the materials, as more energy is requiredfor evaporation. Conversely, bagasse was dried by open air to achieve the useful moisture content for three days. Optimum moisture content varies from the type of feedstock, but it is recommended that a level between 10% and 15% is maintained (Asamoa, 2016).

2.2.2. Adjustment of the Particle Size

The particle size adjustment of both the sewage sludge and bagasse was made through grinding and an electrical milling machine respectively. The dried sewage sludge was crushed through a hammer and then grinded by the grinding machine. Similarly, the bagasse was grinded by the milling machine and the sieve used to obtain the material was sieve 6mm.

It was vital to adjust the particle size to allow durable briquette to be produced. When mixing different particle size materials, inter-particle bonding with nearly no inter-particle spaces between elementswas created, and this yielded briquettes with high impact and tensile strength. According to many studies, the recommended particle size of biomass used for producing both charcoal-based and non-carbonized briquettes ranged below 6mm. The recommended size of dry sludge material was obtained from grinding while dried bagasse will be shredded into the small particle by use of an electrical milling machine.

2.2.3. Carbonization

The gasifier stove carried out carbonization of both sewage sludge and bagasse. The firewas lit in the pyrolysis chamber, and the fuel was poured in through the inlet and covered with the lid. The gasifier stove was left to carbonize the material until there was no more observation of smoke from the ventilation. After cooling of the article, it was removed from the gasifier stove and poured into the airtight container.

Carbonization or pyrolysis is an irreversible chemical change brought about by the action of heat energy in an atmosphere devoid of oxygen (Manassah, 2014). Carbonization of the dried sewage sludge in a kiln aids in the kills pathogen. Carbonization of dried sludge with the addition of sawdust will be at a temperature of 300^0c.

2.2.4. Briquetting

The different ratios of 1:0, 1:1, 2:1, 3:1, and 3: weight determined 2 of sludge to bagasse of the briquettes. The ratios were prepared by measuring the various weights to make a kilogram of each briquette ratio. 15% molasses (by weight) was also measured and added to the differentrates. 50% water (by weight) was also measured and combinedto each ratio. The rates were then hand mixed to make a homogeneous mixture of briquetting.The briquetting machine was switched on, and the mixtures poured into it to make the various briquette samples. The briquettes were then sized to make cylindrical briquettes of diameter 3cm and height of 3cm. Thereafter, the briquettes were dried for 48 hours at a temperature of 75^0C to attain the recommended moisture content.

In briquetting technology, binders are added to raw materials that cannot densify alone to form strong briquettes. The addition of a binder results in enhanced bonding and more stable properties. The control experiment gave the original features of the feedstock before mixing.

2.3. Tests Performed on the Briquettes

2.3.1. Determination of Calorific Value

Calorific value is the amount of energy per Kg produced when a material is burnt. The calorific value calculated was compared to that of wood briquettes. 1 gram of the briquette sample was consumed in a bomb calorimeter, an atmosphere of oxygen under a pressure of about 30 atmospheres. Since the briquettes were poor in the ignition, paraffin was added to the samples. The briquette sample was placed inside the bomb and was then ignited electrically. The bomb was placed in 0.5cc water. The heat dissipated was absorbed in the water. The rise in temperature of the water was then measured. The minimum and the maximum temperatures were noted and were used in the determination of the calorific value. Calorific value is given by:

$$\frac{(Waterequivalent(g) + Waterquantityoftheinnercylinder(g) * RisedTemperature(°C) - calorycorrection}{Quantity\ of\ sample(g)} \quad \ldots$$

Water equivalent (quantity) =

$$\frac{(Calorific\ value\ of\ benzoic\ \left(\frac{cal}{g}\right) * Weight\ of\ benzoic\ acid - Water\ quantity\ of\ inner\ cylinder(g)}{Rised\ Temperature(°C)}$$

2.3.2. Determination of Briquette Burning Rate

Briquette sample of known weight was be placed on wire gauze, and the burner ignited. The heater was in turn placed on a mass balance monitored to record instantaneous measurements of the mass every 10 seconds throughout the combustion process using a stopwatch until the briquette was wholly burnt and a constant weight was obtained. Weight loss at a specific time was computed from the expression:

Burning rate = $\frac{total\ weight\ of\ the\ burnt\ briquette}{total\ time\ taken}$

2.3.3. Determination of Ash Content

The residue left after the burning of coal is known as ash. It is generally composed of inorganic substances. 1g of the sample briquettes was weighed in a silica basin, W_1. The basinswere kept inside a muffle furnace, and the temperature was increased gradually up to 800^0c. The temperature was kept constant for an hour for the incineration of the briquette. After combustion, the basins were allowed to cool after which they were transferred to a desiccator for cooling. The basin was then re-weighed and the weight, $W_{2,}$ recorded.

Ash Content %= $\frac{W2-W3}{W2-W1}\ x\ 100$

Where: W_1 = Weight of crucible (g)

W_2 = Weight of crucible+ briquette before burning (g)

W_3 = Weight of crucible+ briquette after burning (g)

2.3.4. Determination of Volatile Matter

The volatile matter consists mainly of the gases, water and tarry vapors evolved from briquettes when heated at high temperatures.

1g of each of the briquette samples was placed in a silica crucible with a porous silica cover. The weight of the silica crucible and sample was measured and recorded as $W_{1.}$ The cover was used to avoid oxidation. The sample was then heated for 7 minutes at a constant temperature of 925^0C inside a furnace. After heating the crucible, it was transferred to a desiccator for cooling. After that the silica crucible was re-weighed and recorded as $W_{2.}$

Apparent volatile matter = $\frac{W2-W3}{W2-W1}\ x\ 100$

Where: W_1 = Weight of crucible (g)

W_2 = Weight of crucible+ briquette before burning (g)

W_3 = Weight of crucible+ briquette after burning (g)

The actual volatile matter was obtained by:

Actual volatile matter = Apparent volatile mater – moisture content

2.3.5. Determination of Fixed Carbon

Fixed carbon represents the carbon content in a briquette. The amount of fixed carbon was computed by subtracting the sum of the percentage of moisture, volatile matter and ash from 100.

FC = 100 – (moisture % + ash % + volatile %)

2.3.6. Determination of Moisture Content

Moisture content can be expressed either on a dry basis (the weight of the moisture contained in the material divided by the weight of dry material) or wet basis (the weight of the moisture divided by the as-received weight of moisture plus dry matter. Using the standard Moisture Content procedure, moisture content was calculated as follows:

MC% = $\frac{W2-W3}{W3-W1}$ x 100

Where: W_1 =Weight oftin (g)

W_2 = Weight of moist sample + tin (g)

W_3 = Weight of dried soil + tin (g)

2.3.7. Determination of the Shattering Index

The briquette samples were dropped at a specific height of 1.5m onto a solid base. The fraction of the briquette retained was used as an index of briquette breakability. (Tembe, 2014)

Percentage weight loss= $\frac{weight\ loss}{initial\ weight\ of\ briquette\ before\ shattering}$

Shatter resistance = 100- percentage weight loss

3. Data, Data Analysis, Results and Discussion

3.1. Data

3.1.1. Calorific Value

The bomb calorimeter was used to determine the calorific value of the briquettes. This test was used as the criteria for determining the best briquette ratio. The procedure was followed carefully and the raw data obtained from the experiment is shown in the tables below

BENZOIC ACID					
AMBIENT TEMPERATURE 20.1 °C					
BEFORE IGNITION			AFTER IGNITION		
Time (sec)	Temperature °C		Time (sec)	Temperature °C	
	Inner tank	Outer tank		Inner tank	Outer tank
0	1.1	0.87	0	0.9	1
30	1.15	0.88	20	3.3	2
60	1.2	0.88	40	3.3	2
90	1.2	0.88	60	3.3	2
120	1.2	0.89	80	3.3	2.01
150	1.2	0.89	100	3.3	2.02
180	1.2	0.9	120	3.3	2.03
210	1.2	0.9	140	3.3	2.03
240	1.2	0.91	160	3.3	2.2
270	1.2	0.91	180	3.3	2.23
300	1.2	0.91	200	3.3	2.25
330	1.2	0.91	220	3.3	2.25

Table 1: Recorded Temperatures of Benzoic Acid

RATIO 1:0					
AMBIENT TEMPERATURE 22 °C					
PARAFFIN ADDED 0.5g					
BEFORE IGNITION			AFTER IGNITION		
Time (sec)	Temperature °C		Time (sec)	Temperature °C	
	Inner tank	Outer tank		Inner tank	Outer tank
0	0.9	0.96	0	1	0.99
30	0.9	0.97	20	1.3	1.23
60	0.9	0.97	40	1.4	1.37
90	0.9	0.97	60	1.9	1.76
120	0.9	0.97	80	2.3	2.01
150	0.9	0.97	100	2.4	2.35
180	1	0.97	120	2.4	2.35
210	1	0.97	140	2.5	2.35
240	1	0.97	160	2.5	2.35
270	1	0.97	180	2.5	2.35
300	1	0.97	200	2.5	2.35

Table 2: Recorded Temperatures of Ratio 1:0

RATIO 1:1					
AMBIENT TEMPERATURE 20 °C					
PARAFFIN ADDED 0.5g					
BEFORE IGNITION			AFTER IGNITION		
Time (sec)	Temperature °C		Time (sec)	Temperature °C	
	Inner tank	Outer tank		Inner tank	Outer tank
0	0.9	0.89	0	1.2	0.99
30	0.9	0.89	20	1.6	1.26
60	0.9	0.9	40	1.9	1.75
90	0.9	0.9	60	2.3	2.21
120	0.9	0.9	80	2.5	2.47
150	0.9	0.9	100	2.9	2.87
180	0.9	0.91	120	2.9	2.89
210	0.9	0.91	140	3.3	3.23
240	0.9	0.91	160	3.35	3.24
270	0.9	0.92	180	3.35	3.4
300	0.9	0.92	200	3.35	3.4

Table 3: Recorded Temperatures of Ratio 1:1

RATIO 2:1					
AMBIENT TEMPERATURE 22 °C					
PARAFFIN ADDED 0.5g					
BEFORE IGNITION			AFTER IGNITION		
Time (sec)	Temperature °C		Time (sec)	Temperature °C	
	Inner tank	Outer tank		Inner tank	Outer tank
0	0.4	0.5	0	0.7	0.61
30	0.4	0.5	20	0.9	0.83
60	0.4	0.5	40	1.1	0.97
90	0.5	0.51	60	1.2	1.16
120	0.5	0.51	80	1.2	1.16
150	0.5	0.51	100	1.2	1.17
180	0.5	0.52	120	1.2	1.19
210	0.5	0.52	140	1.2	1.19
240	0.5	0.52	160	1.2	1.19
270	0.5	0.52	180	1.2	1.19
300	0.5	0.53	200	1.2	1.19
330	0.5	0.53	220	1.2	1.19
360	0.5	0.54	240	1.2	1.19

Table 4: Recorded Temperatures of Ratio 2:1

RATIO 3:1					
AMBIENT TEMPERATURE 21.8 °C					
PARAFFIN ADDED 0.5g					
BEFORE IGNITION			AFTER IGNITION		
Time (sec)	Temperature °C		Time (sec)	Temperature °C	
	Inner tank	Outer tank		Inner tank	Outer tank
0	0.8	0.83	0	0.9	0.92
30	0.9	0.83	20	1	0.95
60	0.9	0.835	40	1.5	1.58
90	0.9	0.84	60	2.1	2.21
120	0.9	0.84	80	2.2	2.21
150	0.9	0.85	100	2.3	2.21
180	0.9	0.86	120	2.4	2.4
210	0.9	0.86	140	2.4	2.4
240	0.9	0.86	160	2.5	2.59
270	0.9	0.87	180	2.5	2.58
300	0.9	0.87	200	2.5	2.58
330	0.9	0.88	220	2.5	2.58
360	0.9	0.89	240	2.5	2.58

Table 5: Recorded Temperatures of Ratio 3:1

RATIO 3:2					
AMBIENT TEMPERATURE 20.1 °C					
PARAFFIN ADDED 0.5g					
BEFORE IGNITION			AFTER IGNITION		
Time (sec)	Temperature °C		Time (sec)	Temperature °C	
	Inner tank	Outer tank		Inner tank	Outer tank
0	1.1	0.99	0	1.2	1.13
30	1.1	1.01	20	2.5	2.48
60	1.1	1.02	40	2.8	2.96
90	1.1	1.03	60	3.1	3.19
120	1.1	1.04	80	3.1	3.2
150	1.1	1.04	100	3.3	3.2
180	1.1	1.04	120	3.37	3.25
210	1.1	1.05	140	3.37	3.28
240	1.1	1.06	160	3.37	3.29
270	1.1	1.07	180	3.37	3.3
300	1.1	1.08	200	3.37	3.3
330	1.1	1.08	220	3.37	3.4
360	1.1	1.09	240	3.37	3.41

Table 6: Recorded Temperatures of Ratio 3:2

3.1.2. Determination Of Physical And Mechanical Properties Of Briquettes

To determine the physical and mechanical properties of the briquettes, various test was carried out which include: Burning rate, ash content, volatile matter, moisture content and shattering Index.

3.1.2.1. Burning Rate

The burning rate of the various briquette ratios was determined through the observation of the total time taken to consume a given weight of a briquette sample. The data obtained from the test are as shownin table 7 below.

Burning rate of the briquettes						
Time	**Weight of the samples (g)**					
	1:00	**1:01**	**2:01**	**3:01**	**3:02**	**charcoal**
0	0.53	0.43	0.46	0.45	0.36	0.4
10	0.5	0.34	0.44	0.44	0.33	0.39
20	0.48	0.33	0.41	0.43	0.31	0.39
30	0.47	0.32	0.4	0.41	0.29	0.38
40	0.46	0.3	0.39	0.4	0.28	0.38
50	0.45	0.3	0.38	0.37	0.26	0.38
60	0.44	0.29	0.37	0.37	0.24	0.38
70	0.44	0.29	0.36	0.36	0.22	0.38
80	0.44	0.28	0.34	0.36	0.2	0.37
90	0.42	0.27	0.33	0.36	0.18	0.36
100	0.41	0.25	0.29	0.34	0.17	0.36
110	0.41	0.25	0.29	0.33	0.17	0.36
120	0.41	0.22	0.27	0.33	0.16	0.36
130	0.4	0.2	0.26	0.32	0.16	0.35
140	0.4	0.16	0.25	0.32	0.16	0.34
150	0.39	0.14	0.23	0.31	0.13	0.34
160	0.39	0.14	0.23	0.31	0.12	0.34
170	0.38	0.13	0.23	0.29	0.11	0.34
180	0.38	0.12	0.22	0.29	0.09	0.33
190	0.37	0.1	0.21	0.29	0.07	0.33
200	0.37	0.08	0.2	0.29	0.03	0.33
210	0.36	0.07	0.18	0.28	0	0.32
220	0.36	0.06	0.17	0.26		0.31
230	0.36	0.03	0.16	0.26		0.31
240	0.35	0.03	0.15	0.25		0.31
250	0.35	0	0.15	0.25		0.31
260	0.35		0.14	0.24		0.29
270	0.34		0.13	0.23		0.29
280	0.34		0.11	0.22		0.27
290	0.33		0.1	0.22		0.26
300	0.32		0.09	0.21		0.26
310	0.32		0.09	0.2		0.26
320	0.3		0.09	0.2		0.26
330	0.3		0.08	0.19		0.26
340	0.3		0.07	0.19		0.26
350	0.3		0.06	0.18		0.26
360	0.3		0.06	0.18		0.26

Burning rate of the briquettes						
Time	Weight of the samples (g)					
	1:00	**1:01**	**2:01**	**3:01**	**3:02**	**charcoal**
370	0.3		0.05	0.17		0.26
380	0.3		0.04	0.17		0.25
390	0.29		0.03	0.16		0.24
400	0.29		0	0.16		0.24
410	0.29			0.15		0.24
420	0.29			0.15		0.24
430	0.29			0.15		0.23
440	0.29			0.13		0.22
450	0.29			0.12		0.21
460	0.28			0.11		0.21
470	0.28			0.1		0.19
480	0.27			0.1		0.18
490	0.27			0.1		0.18
500	0.26			0.09		0.18
510	0.26			0.08		0.18
520	0.25			0.08		0.18
530	0.23			0.08		0.18
540	0.22			0.07		0.17
550	0.2			0.07		0.17
560	0.2			0.07		0.17
570	0.2			0.06		0.16
580	0.2			0.06		0.16
590	0.2			0.06		0.15
600	0.19			0.06		0.15
610	0.19			0.05		0.15
620	0.18			0.03		0.15
630	0.18			0		0.15
640	0.18					0.14
650	0.17					0.13
660	0.17					0.12
670	0.17					0.11
680	0.17					0.11
690	0.16					0.1
700	0.16					0.1
710	0.15					0.1
720	0.14					0.1
730	0.14					0.1
740	0.14					0.1
750	0.14					0.1
760	0.12					0.1
770	0.12					0.09
780	0.12					0.08
790	0.11					0.07

Burning rate of the briquettes						
Time	Weight of the samples (g)					
	1:00	**1:01**	**2:01**	**3:01**	**3:02**	**charcoal**
800	0.11					0.07
810	0.11					0.06
820	0.11					0.06
830	0.11					0.06
840	0.1					0.05
850	0.1					0.04
860	0.09					0.03
870	0.09					0.02
880	0.09					0
890	0.09					
900	0.09					
910	0.09					
920	0.09					
930	0.08					
940	0.07					
950	0.07					
960	0.06					
970	0.06					
980	0.05					
990	0.04					
1000	0.04					
1010	0.04					
1020	0.04					
1030	0.04					
1040	0.04					
1050	0.04					
1060	0.03					
1070	0.03					
1080	0.01					
1090	0					

Table 7: Burning Rate of Briquettes

3.1.2.2. Ash Content

The ash content of the briquettes was determined through the detailed procedure. The data recorded is illustrated in table 8 below.

Sample	Weight of crucible(g)	Weight of crucible+ briquette before burning(g)	Weight of crucible + briquette after burning(g)	Weight loss(g)
1:0	24.595	25.6	25.188	0.412
1:1	25.631	26.644	26.1961	0.4479
2:1	25.349	26.363	25.867	0.496
3:2	25.985	26.991	26.504	0.487
3:1	37.92	38.856	38.43	0.426

Table 8: Ash Content Data

3.1.2.3. Volatile Matter

The apparent volatile matter of the briquettes was obtained as described in the procedure. The data recorded is as in table 9 below;

Apparent volatile matter of the briquettes				
Sample	**Weight of crucible(g)**	**Weight of crucible+ briquette before burning(g)**	**Weight of crucible+ briquette after burning(g)**	**Weight loss(g)**
1:0	25.99	27.01	26.595	0.415
1:1	24.598	25.599	25.237	0.362
2:1	25.356	26.368	25.863	0.505
3:2	25.632	26.634	26.154	0.48
3:1	37.953	38.957	38.447	0.51

Table 9: Volatile Matter Data

3.1.2.4. Moisture Content

The standard procedure for the determination of moisture content was followed and the data recorded are tabulated in table 10 below.

Moisture Content of the briquettes				
Sample	**Weight of tin(g)**	**Weight of tin+ sample before heating(g)**	**Weight of tin +sample after heating(g)**	**Weight loss(g)**
1:0	8.5	29	28.5	0.5
1:1	8.6	40.5	39	1.5
2:1	8.7	38	36.5	1.5
3:1	8.6	42	40	2
3:2	8.6	33	32	1
Charcoal	8.5	15	15	0

Table 10: Moisture Content Data

3.1.2.5. Shattering Index

Shattering index, which is a measure of determining the briquette breakability was carried out. The data from the experiment is tabulated as shown in table 11 below.

Shattering Index of the Briquettes			
Ratio	**weight of briquette (g)**	**weight after shattering (g)**	**Weight loss (g)**
1:0	34.5	32.5	2.0
1:1	29	23.5	5.5
2:1	27.5	26.5	1.0
3:1	27.5	25	2.5
3:2	34	31.5	2.5

Table 11: Shattering Index Data

3.2. Results and Data Analysis

3.2.1. Calorific Value

The raw data was analysed and calorific values were obtained for the different briquette samples as shown in table 12 below:

BriquetteSample (Sludge: Bagasse)	Calorific value(call/g)
1:0	2053.01
3:1	2139.4
2:1	2510.94
3:2	2800.3
1:1	2965.68

Table 12: Calorific Values of Different Ratios

3.2.2. Determination of Physical Properties of the Briquettes

3.2.2.1. Burning Rate

The data obtained from the experiment was analysed and the following results in table 13 below were obtained;

BriquetteSample (Sludge: Bagasse)	Burning Rate (g/sec)
1:0	$4.86*10^{-4}$
3:1	$3.98*10^{-4}$
2:1	$1.18*10^{-3}$
3:2	$1.8*10^{-3}$
1:1	$4.6*10^{-4}$

Table 13: Burning Rate of the Various Ratios

3.2.2.2. Ash Content

The results of the different ratios of briquettes obtained from data analysis is depicted in table 14 below.

Sample (Sludge: Bagasse)	Weight of crucible(g)	Weight of crucible+ briquette before burning (g)	Weight of crucible + briquette after burning(g)	Weight loss(g)	Ash content(%)
1:0	24.595	25.6	25.496	0.104	10.348
1:1	25.631	26.644	26.524	0.12	11.846
3:1	37.92	38.856	38.742	0.114	12.179
3:2	25.985	26.991	26.858	0.133	13.221
2:1	25.349	26.363	26.224	0.139	13.708

Table 14: Ash Content of Briquettes Samples

3.2.2.3. Volatile Matter

From the data analysis, the actual volatile matter was derived for the various briquette sample ratio. The real volatile matterwas determined by the subtraction of the moisture content from the apparent volatile matter for each briquette sample. Table 15 below shows the actual volatile matter of the samples.

Actual Volatile Matter			
Briquette sample (Sludge: Bagasse)	Apparent volatile matter(%)	Moisture content (%)	Actual volatile matter(%)
1:1	35.49	4.71	30.79
1:0	40.69	2.44	38.25
3:2	47.06	4.10	42.96
3:1	50	5.99	44.01
2:1	49.51	5.12	44.39

Table 15: Actual Volatile Matter of Various Samples

3.2.2.4. Moisture Content

From data analysis, the following results were obtained as tabulated below

Moisture Content of the briquettes					
Sample (Sludge: Bagasse)	Weight of tin(g)	Weight of tin+ sample before heating(g)	Weight of tin +sample after heating(g)	Weight loss(g)	Moisture content(%)
1:0	8.5	29	28.5	0.5	2.4390
3:2	8.6	33	32	1	4.0984
Charcoal	8.5	15	14.7	0.3	4.6154
1:1	8.6	40.5	39	1.5	4.7022
2:1	8.7	38	36.5	1.5	5.1195
3:1	8.6	42	40	2	5.9880

Table 16: Moisture Content of Briquette Samples

3.2.2.5. Shattering Index

Shatter resistance of the various briquette samples after data analysis is shown below

Briquette sample (Sludge: Bagasse)	The weight of briquette (g)	Weight after shattering (g)	Shattering weight(g)	Shattering index	Shatter resistance (%)
2:1	27.5	26.5	1	3.6364	96.3636
1:0	34.5	32.5	2	5.7971	94.2029
3:2	34	31.5	2.5	7.3529	92.6471
3:1	27.5	25	2.5	9.0909	90.9091
1:1	29	23.5	5.5	18.9655	81.0345

Table 17: Shatter Resistance of Various Briquettes Samples

<u>3.2.3. Sample Calcuation</u>

3.2.3.1. Calorific Value

Calorific value of benzoic acid (cal/g) = 6318 cal/g

Weight of benzoic acid (g) = 1.093 g

Rise in Temperature $T_{max} = 3.3\ ^oC$ $T_{min} = 1.2\ ^oC$

$T_{max} - T_{min}$ 3.3 – 1.2 =1.1°C

Water quantity in inner cylinder = 2100 g

$$\frac{6318\text{x } 1.093}{1.1} - 2100 = 1188.37 \text{ g}$$

Calorific value ratio 1:1

$$\frac{1188.37 + 2100\text{x}(3.35 - 0.9)}{1.061} = 5931.36 \text{ g}$$

0.7 g of paraffin was used: Calory correction 0.7 x calorific value

Therefore, corrected calorific value will be 0.7 x 5931.36 = 2965.68 cal/g

3.2.3.2. Burning Rate

Burning rate = $\frac{\text{total weight of the burnt briquette}}{\text{total time taken}}$

Considering ratio 1:1

Total weight of the burnt briquette = 0.43 g

Total time taken = 250 sec

$$\frac{0.43 \text{ g}}{250 \text{ sec}} = 1.72 \text{ x } 10^{-3} \text{ g/sec}$$

3.2.3.3. Ash Content

Considering ratio 1:1

Ash Content % = $\frac{W2-W3}{W2-W1}\ x\ 100$

Where: W_1= Weight of crucible(g) W_1 = 25.631 g

W_2 = Weight of crucible+ briquette before burning (g) W_2 = 26.196 g

W_3 = Weight of crucible+ briquette after burning (g) W_3 = 25.631 g

$$\frac{26.644 - 26.196}{26.644 - 25.631}\text{x } 100 = 44.23\ \%$$

3.2.3.4. Moisture Content

Considering ratio 1:1

MC% = $\frac{W2-W3}{W3-W1}$x 100

Where: W_1 =Weight oftin (g) =8.6 g

W_2 = Weight of moist sample + tin (g)= 40.5

W_3 = Weight of dried soil + tin (g) = 39 g

$$\frac{40.5 - 39}{39 - 8.6}\text{x } 100 = 4.9342\%$$

3.2.3.5. Volatile Matter

Considering ratio 1:1

Apparent volatile matter = $\frac{W2-W3}{W2-W1}$ x 100

Where: W_1= Weight of crucible(g) W_1 = 24.598 g

W_2 = Weight of crucible+ briquette before burning (g) W_2 = 25.599 g

W_3 = Weight of crucible+ briquette after burning (g) W_3 = 25.237 g

$$\frac{25.599 - 25.237}{25.599 - 24.598} \times 100 = 36.1638\ \%$$

Actual volatile matter = Apparent Volatile Matter – Moisture content
= 36.1638 % - 4.9342%
= 31.2296%

3.2.3.6. Fixed Carbon
FC = 100 – (moisture % + ash % + volatile %)
Considering ratio 1:1
Moisture % = 4.9342
Ash% = 44.23
Volatile % = 31.2296
= 100 - (4.9342+44.23+31.2296) = 19.6062 %

3.2.3.7. Shattering Index
Considering ratio 1:1

Percentage weight loss % = $\frac{\text{weight loss}}{\text{initial weight of briquette before shattering}}$

Weight loss = 5.5g
Initial weight = 29.0 g

$\frac{5.5}{29.0}$X 100 = 18.966%

Shatter resistance = 100- percentage weight loss
= 100 – 18.966
= 81.034%

3.3. Discussion of Results

3.3.1. Summary of Physical Properties of Briquettes

The results obtained are used to determine the physical properties of fuel briquettes in comparison to wood charcoal briquettes and are shown in table 17 below;

Physical Properties Of Fuel Briquettes And Wood Charcoal Briquettes						
Parameters	**Briquettesample (Sludge :Sugarcane Bagasse)**					**Wood charcoal briquette Standards**
	1:1	**3:2**	**2:1**	**3:1**	**1:0**	
Calorific value(cal/g)	2965.68	2800.3	2510.94	2139.4	2053.01	**≥ 5000**
Ash content (%)	11.846	13.221	13.708	12.179	10.348	**3% -10%**
Moisture Content (%)	4.702	4.088	5.119	5.988	2.439	**5%-10%**
Fixed Carbon (%)	53.024	40.762	40.142	38.154	48.965	**60% -80%**
Volatile matter (%)	30.788	42.9604	44.390	44.012	38.247	**15% -28%**
Shattering index (%)	18.966	7.353	3.6363	9.091	5.797	**4%-15%**

Table 18: Summary of the Physical Properties of Fuel Briquettes

3.3.1.1. Calorific Value

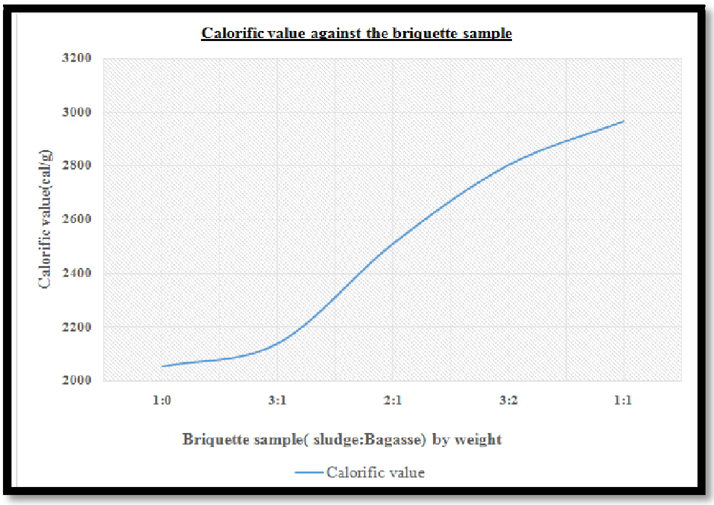

Figure 1: Graphical Representation of the Calorific Value

From the graph, the calorific value of the briquettes was between 2053.01 cal/g and 2965.68 cals/g for the briquette samples 1:0 and 1:1 respectively. In comparison to that of charcoal, which has a calorific value of 5000 cal/g, the values obtained are lower.

Calorific value determines the amount of energy dissipated during complete combustion of a unit mas of the briquette.A high calorific value indicates that a briquette has a high burning capability while low calorific value shows poor burning capacity.

Although charcoal is a superior fuel, the calorific value of briquette sample 1:1 was 2965.68 cal/g which is the best performing briquette. It is also evident that the calorific value is highly dependent on the mixture ratio of sludge to bagasse.

3.3.1.2. Moisture Content

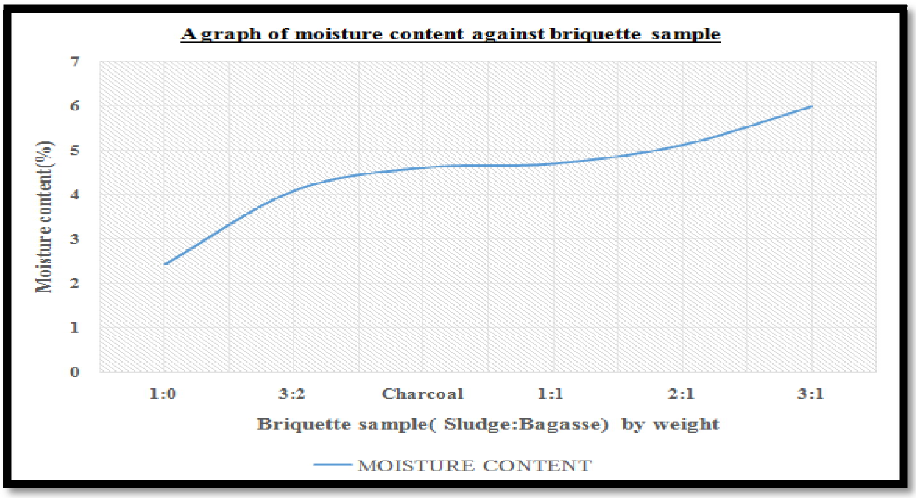

Figure 2: Graphical Representation of Moisture Content of Briquette Samples

As illustrated from the graph, the moisture content of the briquettes ranged between 2% and 6%, with briquette sample (1:0) having the lowest moisture content while briquette sample (3:1) has the highest moisture content. The moisture content of wood charcoal as shown in table 18 is 5-6%.

Moisture content is crucial when it comes to refuse-derived fuel processing. Low moisture content indicates that the feedstock was adequately dried before briquetting and after briquetting. This leads to better handling and transportation of the briquettes. Low moisture content also improves the calorific value of the briquette, hence increasing its burning capability.

In the case of briquette sample 1:0, which has very low moisture, this may lead to the roughness of the briquettes leading to the inadequate bonding of particles. The optimum moisture content was that of charcoal, which was used as a control. Therefore briquette samples 1:1, 2:1 and 3:1 are within the acceptable range of moisture content.

3.3.1.3. Ash Content

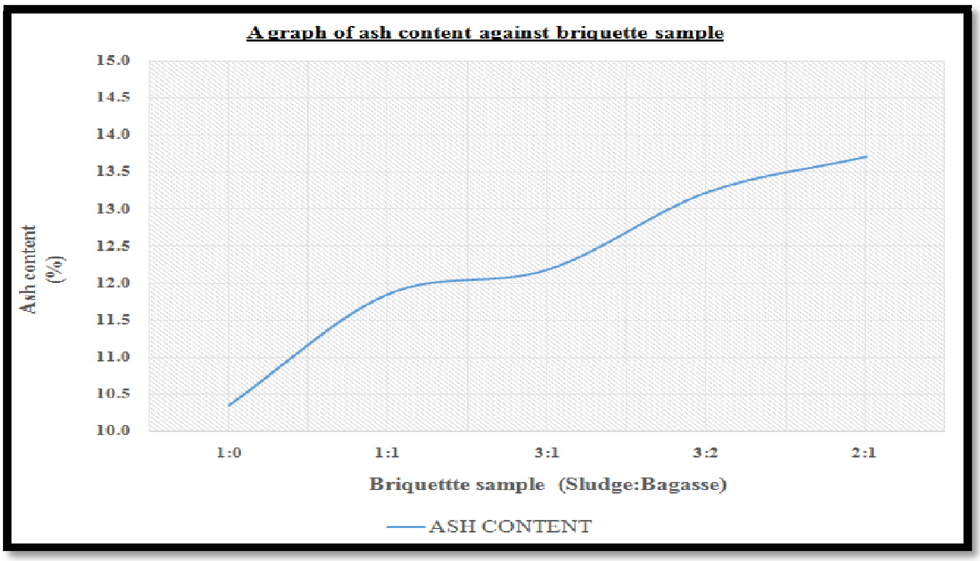

Figure 3: Graphical Representation of Ash Content of Briquette Samples

As depicted from the graph, ash content was in the range of 10.348% and 13.708% for the various briquette sample. The briquette sample 1:0 had the lowest ash content, while ratio 2:1 had the highest value. In contrast to that of charcoal, whose values range from 3-10 %, as shown in table 18, the values obtained are very high.
High ash content indicates that there is the presence of alkaline earth metals in the feedstock used. Alkaline earth metals components have low fusion temperature, which leads to an increment in the lagging potential. (Asamoa, 2016)
Additionally, the high ash content leads to slagging behavior due to the high production of ash. This can be improved by increasing the density of the briquette by compaction, hence reducing the combustion area of the briquette.

3.3.1.4. Shattering Index

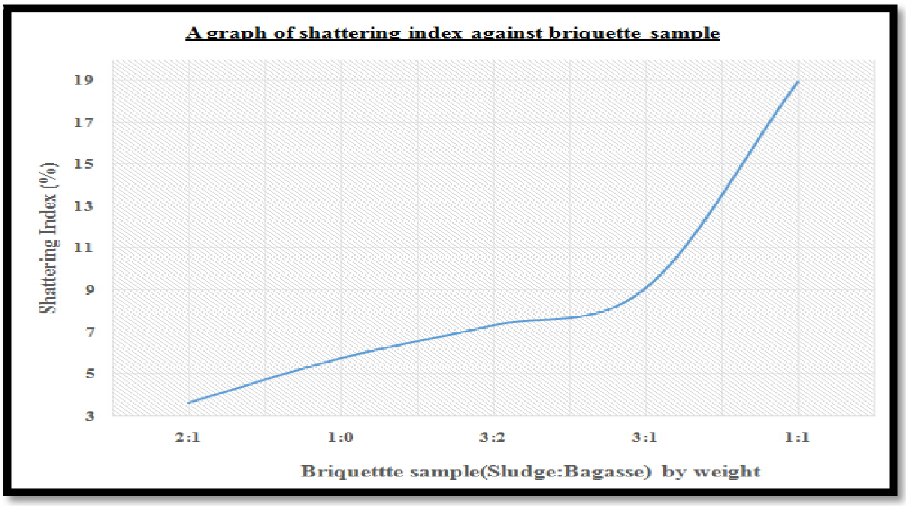

Figure 4: Graphical Representation of the Shattering Index of Briquette Samples

From the graph shown above, the shattering index is in the range of 3.6363% and 18.9655% for briquette sample 2:1 and briquette sample 1:1 respectively. In comparison to wood charcoal values, which range from 4%-5%, ratio 2:1 and ratio 1:0 have an acceptable shattering index.

Shattering index affects the handleability of the briquettes. The low shattering index is considered, which is an indication that the briquettes can easily be handled and transported. The briquette sample Ratio 1:1 has a very high shatter index, which has to be improved. This can be enhanced by increasing the compressive strength of the briquette by addition of a binder
From the values obtained, the shattering index is considerable thus making the briquettes are more natural to transport, handle and store, hence making them an efficient alternative source of fuel.

3.3.1.5. Actual Volatile Matter

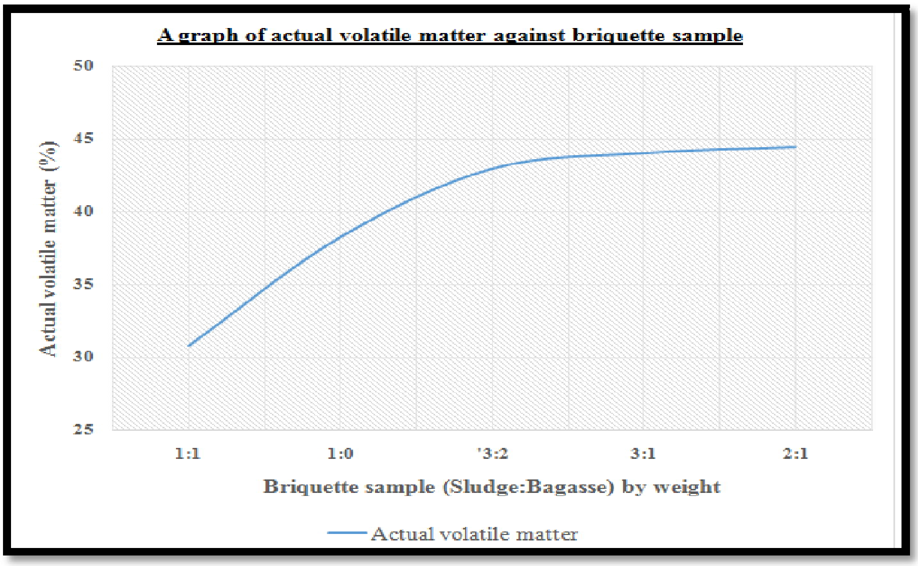

Figure 4: Graphical Representation of the Actual Volatile Matter of Briquette Samples

From the graph above, the volatile matter was in the range of 30.788% and 44.39% for briquette sample 1:1 and 2:1 respectively. Volatile matter of wood charcoal ranges from 15% - 28% as shown in table 18. It is evident that briquette sample 1:1 has a volatile matter closer to that of charcoal.

The low volatile matter is crucial which shows that there is the minimum emission of gases, which is a primary concern to the users. The values obtained are relatively low compared to that of other feedstocks (Asamoa, 2016) . Briquette sample 1:1 has a higher volatile matter compared to that of wood charcoal, which can be improved by proper carbonization. The main aim of carbonization is to get rid of toxic gas emissions that may be harmful to the user.

Therefore, the briquettes (ratio 1:1), should be used in the well-aerated environment to enhance proper discharge of the volatile matter which may pose health risks to the users.

3.3.1.6. Fixed Carbon

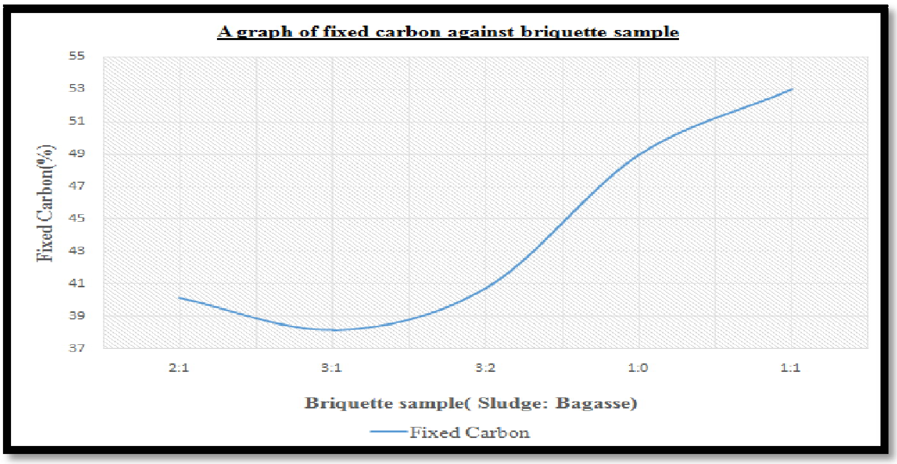

Figure 5: Graphical Representation of Fixed Carbon of Briquette Samples

From the graph above, the briquettes had fixed carbon content between 38.154% and 53.028% for briquette sample 2:1 and 1:1 respectively. In contrast to wood charcoal whose values range from 60% -80% as depicted in table 18, ratio 1:1 has the closest amount of fixed carbon compared to the other rates.

High carbon content indicates that the briquettes have a high burning capability. This is attributed by carbonization of the feedstock before the briquetting process. High carbon content also shows that the briquettes produced are long lasting, thus have a higher burning rate. (Asamoa, 2016)

The high fixed carbon content for ratio 1:1 indicate that the briquette sample has good combustion properties. This can be confirmed by the high calorific value of the briquette. Fixed carbon increases with less ash and moisture content of a briquette.

4. Conclusion and Recommendations

4.1. Conclusion

Investigation of the physical and mechanical properties of the sludge and bagasse briquettes were carried out. The following conclusions were made:

1. The sample with the sludge and sugarcane bagasse proportions of 1:1 by weight, was the best performing briquette since it had the highest calorific value of 2965.68 cal/g. However, this value was lower than that of the wood charcoal briquette standard of 5000 cal/g.
2. The briquette sample of 1:1 had the best burning properties since it had the highest fixed carbon content of 53.024%, a low volatile matter of 30.79%, low moisture content 4.7%. These values were close to those of wood charcoal briquette standard. Refer to table 4.12
3. The briquette sample of ratio 1:1 had a high shattering index of 18.97%, implying that the sample has a high likelihood to crumble during handling and transportation.

4.2. Recommendations

The briquettes need to be made more efficient through the reduction of the ash content, the shattering index and the volatile matter content. The compressive strength also has to be improved. This will require more research and development such as the variance of the binder, sieving, reduction of ash content and change in the shape of the briquettes for improved airflow during combustion.

5. Acknowledgement

First, we register our appreciation to God Almighty for His guidance and protection. We thank Mrs. P.M Kibetu, a lecturer in JKUAT for her informed advice throughout the project. Your effort at providing advice is greatly valued. We tender our deep gratitude to Mr. Muigai, Thermodynamics lab technician in JKUAT for his great support throughout the research. We would also like to appreciate our colleagues who guided and assisted us throughout our studies and in accomplishing this research work.

In addition, we would like to thank our family and friends who stood by our side throughout our research. GOD BLESS YOU ALL.

To all those behind the scene who supported us and we have not mentioned, thank you so much. It means a lot and we are greatly humbled.

6. References

i. Ajiboye, TK et al. (2016). Investigation of mechanical properties pf briquette products of sawdust-charcoal as a potential domectic energy source. JAMES ISSN.
ii. Alice Saabye, E. E. (2005). Sludge treatment and disposal management approaches and experience. Environmental Issues Series no. 7.
iii. Asamoa, B. J. (2016). a review on production, marketing and use of fuel briquettes.
iv. AZEUS. (2012). Retrieved November Friday, 3, 2017, from charcoalbriquettemachine.coml: www.charcoalbriquettemachine.com/news/sugarcane-bagasse-in-Kenya.html
v. Buates, J. (April 2013). Characterization of Fuel Briquettes Made from Sewage Sludge Mixed with Water Hyacinth and Sewage Sludge Mixed with Sedge. International Journal of Environmental Science and Development, Vol. 4, No. 2, 179 - 181.
vi. Daham Shyamalee et al. (2015). Evaluation of different binding materials in forming briquettes with saw dust. International Jounal of Scienific and Research.
vii. Florinda T. Bacani et al. (2015). Evaluation of fuel properties of charcoal briquettes derived from combinations of coconut shells, corn cob and sugarcane bagasse. DLSU Research Congress. Manilla.
viii. Jacob K. Kibwage et al. (n.d.). recycling waste into fuel briquettes. organic resource management Kenya.
ix. Manassah, J. (2014). Alternative Energy Sources Part A. Elsevier.
x. N. Supatata, J. B. (2013). Characterization of Fuel Briquettes Made from Sewage Sludge Mixed withWater Hyacinth and Sewage Sludge Mixed with Sedge. International Journal of Environmental Science and Development, Vol 4, N0 2, 179, 180, 181.
xi. NPCS Board of Consultants & Engineers. (2015). Biomass Based Products(Biochemicals, Biofuels, Activated Carbon). Asia Pacific Press.
xii. Silveira, D. S. (2005). Bioenergy- Realizing the potential.
xiii. Silver, A. (2016). Kenyan Startup Uses Sun to Turn Human Waste into Cooking Fuel. IEEE Spectrum.
xiv. Speight, J. G. (2011). The Biofuels Handbook.
xv. Sperling, M. V. (2007). Biological WasteWater Treatment, Sludge Treatment and Disposal.