MAKERERE UNIVERSITY

COLLEGE OF NATURAL SCIENCES
SCHOOL OF PHYSICAL SCIENCES
DEPARTMENT OF CHEMISTRY

ACCESSING THE SUITABLE PARAMETERS FOR THE PRODUCTION OF CARBONIZED BRIQUETTES USING BAGASSE, CLAY AS BINDER AND MOLASES AS A FILLER.

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A Research project submitted to the Department of Chemistry Makerere University as a partial fulfillment for an award of a degree in Bachelor of Science in Industrial Chemistry.

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Declaration

I MUSIIME IVAN BBALA declare that this project report is mine and has never been submitted to any university or institution for higher learning for any academic award.

Signature ....

Date 24/10/2022

Approval

This is to certify that MUSIIME IVAN BBALA a student of Makerere University pursuing **BARCHELOR OF SCIENCE IN INDUSTRIAL CHEMISTRY** has successfully completed his project research course under my supervision.

Signature ....

Date ...17/11/2022...........

DR. DAN EGESA

LECTURER

MAKERERE UNIVERSTY

Dedication

I dedicate this report to my father **MR. ALIGANYIRA JOHN BOSCO** my mother **MRS. KABAHENDA MONICA**, my brothers and sister who have been there for me in terms of facilities whenever I needed them they provided for in time. Thank you very much may the almighty GOD bless the work of your hands.

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ABSTRACT

Sugar Coperation Of Uganda Limited SCOUL generates about 1.5 million tons of sugarcane bagasse per year which has enormous potential for exploitation in modern commercial applications. 0.8 tons of bagasse is used in the cogeneration process during the production of electricity leaving 0.7 tons of bagasse useless and an environmental hazard.

Due to rising fossil fuel prices, availability in large quantity and rapidly growing interest in bio energy as well as technological advances and environmental concerns, bagasse could be utilized for the formulation of carbonized briquettes for household use to supplement wood charcoal. In this study briquettes were formulated using carbonized bagasse, clay as a binder and molasses as a filler. Bagasse was obtained from SCOUL for carbonization.

Carbonization was carried out using a brick-built kiln while blending used a manually operated drum mixer at Josa Green Technologies in Wakiso District. A piston type briquetting press fitted onto a universal strength testing machine was used for the production of briquettes.

The most optimum parameters that produced briquettes which complied with current charcoal specifications for household use were in the ratio of 1:1:40 for molasses, clay and carbonized bagasse respectively at 0.50N/mm2 pressure. At this formulation, briquettes were produced whose ash content, volatile matter and calorific energy were 36.4%, 27.2% and 4.390 Kca/g respectively.

The briquettes produced burnt without sparks and were smokeless, producing no irritating smell. They ignited easily and took relatively long before they extinguished. They were recommended for household use in Uganda.

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ABBREVIATIONS

VM Volatile

CV Calorific Value

FC Fixed Carbon

PMC Percentage moisture content

PFC Percentage fixed carbon

PVM Percentage volatile matter

PAC Percentage ash content

CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

Energy, which is important for the provision of essential services for humanity such as lighting, heating and cooking, is broadly classified into renewable and nonrenewable. The demand for the former which include hydro-power, geothermal, biomass, solar, wind and tidal energy, has been increasing over the years in the 478 European Journal of Sustainable Development (2012), 1, 3, 477-492 developing countries where 1.8 million people in rural and urban centers lack access to commercial energy (UNEP, 2000). Biomass energy accounts for about 14 % of the total world energy compared to coal (12 %), natural gas (15 %) and electric energy (14 %).

In Uganda 84 % of the total energy used by 90 % of the population is derived from biomass sources such as charcoal, firewood, agricultural residues and animal/livestock wastes. Between 1970 and 1994, production and consumption of charcoal doubled and is expected to increase by 5 % up to the year 2010 (WEC, 2003).

The costs of fuel particularly in metropolitan places proceed to rise and are dependent upon occasional vacillations as kindling turns out to be progressively inaccessible. This is additionally exacerbated by the diminishing area region covered by timberland that is assessed from 15% to 26% of Uganda's territory region. Biomass has generally been a modest and open wellspring of fuel for Uganda's populace yet this is probably not going to go on as a high reliance is raising worries for the manageability of the assets as human populaces and contending requests increment. Moreover, the unreasonable exhaustion of woody biomass holds predicts a few unfortunate results for the nation's populace, including expanded energy uncertainty, exorbitant ascent in wood fuel costs, environmental change from deforestation and expanded country metropolitan relocation. The change of timberlands to other land utilizes contributes 38% of Uganda's public GHG outflows (Mulindwa, Egesa et al. 2021).

The briquettes can be utilized in different foundations like schools, lodgings eateries among others supplanting conventional energy sources like charcoal and firewood which are not both ecological and financial well disposed.

Tests show that something like 5kg of charcoal is expected to cook 1kg of beans contrasted with 7kg of firewood required for a similar errand. Not at all like for charcoal and kindling, 1kg of briquettes is required for similar assignment which utilizes briquettes conservative and all the more so natural cordial since there is no requirement for deforestation to acquire energy yet rather more the use of results of existing cycles to deliver energy.

1.2 PROBLEM STATEMENT

The presence of large sums of bagasse at SCOUL which is an environmental problem and may even lead to a fire out break at the factory premises.

1.3 GENERAL OBJECTIVE

The objective of this study was to determine suitable parameters for the formulation of briquettes using molasses, clay and bagasse, their physico-chemical properties and burning and utilization characteristics of the briquettes for household use.

1.4 SPECIFIC OBJECTIVES

1. Carbonize bagasse to obtain bio char
2. Prepare the binding and filling agents i.e. clay and molasses by removing impurities in them.
3. Mix the bio char with the filling and binding agents to obtain carbonized briquettes
4. Measure the physico- chemical properties of the produced carbonized briquettes.

CHAPTER 2: LITERATURE REVIEW

A briquette is a compressed block of coal dust or other combustible biomass materials like charcoals, sawdust, wood chips, peats, bagasse etc. Carbonized briquettes are compressed fuels made from materials burnt in controlled amount of oxygen forming carbon(Hwangdee, Jansiri et al. 2021).

Biomass is currently the most widespread form of renewable energy and its exploitation is further increasing due to the concerns over the devastative impacts of fossil fuel consumption, i.e., climate change, global warming and their negative impacts on human health(Tursi 2019). In line with that, the present articles reviews the different sources of biomass available, along with their chemical composition and properties. Subsequently, different conversion technologies (i.e., thermo-chemical, biochemical, and physic-chemical conversions) and their corresponding products are reviewed and discussed. In the continuation, the global status of biomass *vs.* the other renewable energies is scrutinized. Moreover, biomass-derived energy production was analyzed from economic and environmental perspectives. Finally, the challenges faced to further expand the share of biomass-derived energy carriers in the global energy market are presented (Santos, Ferreira et al. 2022).

The cooking energy blend in Uganda is overwhelmed by natural biomass (as firewood), with charcoal the following most used fuel. In Uganda, around 95% of all Ugandan families depend on charcoal, wood, or different types of biomass for their family cooking needs. As per the Global Alliance for Clean Cook ovens, natural biomass makes up most of cooking powers in Uganda. Late reports have demonstrated that most of rustic families use kindling for cooking while in metropolitan regions families utilize both firewood and charcoal (Mulindwa, Egesa et al. 2021).

Many investigations have shown that biomass, for example, cabbage market squander, bagasse, coconut shells, sugarcane, rice husks, green growth, paper squander, coffee beans, and so forth, can be utilized as crude materials for briquette production.

Improvement of briquettes has been effectively investigated because of its capability to address farming garbage removal issue and as an elective choice to current energy assets. Presently, biomass briquettes generally utilized for homegrown and modern purposes like cooking, warming and power age.

Direct use of agricultural residuals as fuel is normally characterized by low efficiency. Also the low bulk density of the residues often makes them uneconomical to store or transport. One method to overcome their difficulties is to density and carbonize them. The carbonized briquette develops a higher temperature in stoves and furnaces and has the advantages of relatively smokeless combustion. As it does not rot and it not attacked by termites, fungus, etc., the storage losses are relatively very low (Mulindwa, Egesa et al. 2021).

The primary targets of the review were to comprehend and enhance the course of production of carbonized briquettes for expanding the nature of the delivered briquette and prescribe the best restricting material to be utilized during creation process. The underlying job to be played is to carbonize the natural substance which is biomass waste which is to be mixed with the limiting specialists in this way access their effect on the quality.

Bio char is totally lack of plasticity, thus it needs addition of a binding material to hold the briquette together for transportation, briquette forming and storage. Every particle of char is coated with binder which enhances charcoal adhesion and produces identical briquettes. After the wet pressed briquettes are dried, the binding process is completed(Grover and Mishra 1996).

During production of carbonized briquettes, different binding materials which are as follows: Clay, Starch i.e. cassava flour, Molasses, Arabic gum are used. Besides the binding materials, other additives are also added during manufacture to aid the combustion of briquettes. These include: Accelerant, Ash whitening agent, Press release agent, Fillers(Sengar, Mohod et al. 2012).

The quality of briquettes depends on both physical and chemical parameters .Chemical parameter are Moisture content, volatile matter, fixed carbon, Ash content, heating value while the Physical parameters Bulk density, Drop resistance, Compressive strength(Kers, Kulu et al. 2010).

2.1 BIOMASS

The value of a particular type of biomass depends on the chemical and physical properties of the macromolecules from which it is made. For centuries, people have used the energy stored in chemical bonds in biomass to power things like fires and food. They also get some nutritional benefits from eating plants. More recently, fossil fuels such as coal and oil have been used to generate energy (Obi, Pecenka et al. 2022). However, as biomass must take millions of years to be converted into fossil fuels, these resources are not renewable for human use within a timeframe that is feasible for us. The burning of fossil fuels uses "old" biomass to create "new" CO2, which contributes to the "greenhouse effect" and depletes a non-renewable resource. Burning new biomass only produces carbon dioxide if the plant is then replanted. If the plant is not replanted, the carbon dioxide is absorbed and returned to the atmosphere for new growth. One important factor to consider when using biomass to help alleviate global warming is the time necessary to generate the energy necessary to power the biomass(McKendry 2002).

The issue facing the developed world is the need to take appropriate action to mitigate the lag period. There is a dilemma for the developing world as it consumes biomass resources for fuel, but does not have a programmer of replacing these resources(Thornton, van de Steeg et al. 2009). There are many crops that are being studied for commercial uses of energy. Potential energy crops include woody plants and grasses and herbaceous plants (all perennial crops). Starch and sugar crops are also included, as are oilseeds. The ideal energy crop would have high yields, low energy inputs to produce, little or no environmental toxins, and low nutrient requirements(Obi, Pecenka et al. 2022). Desired characteristics will vary depending on local climate and soil conditions. Water consumption can be a major constraint in many areas of the world, and it makes the drought resistance of the crop an important factor. Other important characteristics of this product include its ability to resist moisture and stains, and its soft, comfortable fabric.

There has been renewed interest in biomass as an energy source over the past decade, with many people looking to it as an alternative to fossil fuels.

There are several reasons for this situation:

First, technological developments in terms of conversion, crop production, etc.; the application of biomass at lower cost and with higher conversion efficiency than has been possible in the past is promised. For example, when bagasse residues are used as fuel, the cost of electricity is often already now competitive with fossil fuel-based power generation. Some more advanced options for producing electricity are proving to be very cost-effective, and allow for a more efficient use of energy crops (Tumuluru, Wright et al. 2011). The production of methanol and hydrogen through gasification processes. This sector is producing food surpluses, which is driving up prices and creating jobs. This situation has led to the development of a policy in which land is set aside in order to reduce surpluses. Related problems, such as the de-population of rural areas and the rise of cities, are causing problems for society.

The threat of climate change, due to high emission levels of greenhouse gases (CO2 being the most important one), has given a major boost to renewable energy sources in general. When bagasse is produced using sustainable methods, it releases about the same amount of carbon dioxide during conversion as the plant takes up during growth (Tumuluru, Wright et al. 2011). The use of biomass does not contribute to a build-up of CO2 in the atmosphere. The main three factors affecting energy security are biomass, indigenous energy sources, and the potential for diversifying fuel supplies, but there are others too(MacCarty, Ogle et al. 2008). Biomass production can generate jobs and, if energy crops are replaced by less intensively managed forms of agriculture, there are likely to be environmental benefits, such as reduced leaching of fertilizers and reduced use of pesticides. In addition, if appropriate plants are selected, restoration of degraded ones(Easterly and Burnham 1996).

2.1.1 Biomass types

Researchers characterize the various types of biomass in different ways but one simple method is to define four main types, namely;

- Woody plants
- Herbaceous plants/grasses
- Aquatic plants
- Manures.

Within this categorization, herbaceous plants can be further subdivided into those with high- and low-moisture contents. Apart from specific applications or needs, most commercial activity has been directed towards the lower moisture-content types, woody plants and herbaceous species and these will be the types of biomass investigated in this study. Aquatic plants and manures are intrinsically high-moisture materials and as such, are more suited to ‘wet’ processing techniques. Based primarily upon the biomass moisture content, the type of biomass selected subsequently dictates the most likely form of energy conversion process (Vassilev, Baxter et al. 2010).

High moisture content biomass, such as the herbaceous plant sugarcane, lends itself to a ‘wet/aqueous’ conversion process, involving biologically mediated reactions, such as fermentation, while a ‘dry’ biomass such as wood chips, is more economically suited to gasification, pyrolysis or combustion(Champagne 2008). Aqueous processing is used when the moisture content of the material is such that the energy required for drying would be inordinately large compared to the energy content of the product formed(McKendry 2002).

However, there are other factors which must be taken into consideration in determining the selection of the conversion process, apart from simply moisture content, especially in relation to those forms of biomass which lie midway between the two extremes of ‘wet’ and ‘dry’. Examples of such factors are the ash, alkali and trace component contents, which impact adversely on thermal conversion processes and the cellulose content, which influences biochemical fermentation processes (Vassilev, Baxter et al. 2010).

2.1.2 Plant characteristics

Biomass contains varying amounts of cellulose, hemicellulose, lignin and a small amount of other extractives.

Woody plant species are typically characterized by slow growth and are composed of tightly bound fibers, giving a hard external surface, while herbaceous plants are usually perennial, with more loosely bound fibers, indicating a lower proportion of lignin, which binds together the cellulosic fibers: both materials are examples of polysaccharides; long-chain natural polymers. The relative proportions of cellulose and lignin is one of the determining factors in identifying the suitability of plant species for subsequent processing as energy crops (Tumuluru, Wright et al. 2011).

Cellulose is a glucose polymer, consisting of linear chains of (1, 4)-D-glucopyranose units, which the units are linked 1–4 in the b-configuration, with an average molecular weight of around 100,000. Hemicellulose is a mixture of polysaccharides, composed almost entirely of sugars such as glucose, mannose, xylose and arabinose and methylglucuronic and galaturonic acids (Tsai 2007).

2.1.3 Bagasse properties

It is the inherent properties of the bagasse source that determines both the choice of conversion process and any subsequent processing difficulties that may arise. Equally, the choice of bagasse source is influenced by the form in which the energy is required and it is the interplay between these two aspects that enables flexibility to be introduced into the use of bagasse as an energy source(Anukam, Mamphweli et al. 2016). As indicated above, the categories of biomass considered in this study are woody and herbaceous species; the two types examined by most biomass researchers and technology providers. Dependent on the energy conversion process selected, particular material properties become important during subsequent processing (Rasul, Rudolph et al. 1999).

The main material properties of interest, during subsequent processing as an energy source, relate to: Moisture content (intrinsic and extrinsic), Calorific value, Proportions of fixed carbon and volatiles, Ash/residue content, Alkali metal content, Cellulose/lignin ratio(McKendry 2002).

For dry bagasse conversion processes, the first five properties are of interest, while for wet bagasse conversion processes, the first and last properties are of prime concern (Mousavioun and Doherty 2010). The quantification of these materials properties for the various categories of biomass is discussed in the following section.

Moisture content

Two forms of moisture content are of interest in biomass: Intrinsic moisture: the moisture content of the material without the influence of weather effects. Extrinsic moisture: the influence of prevailing weather conditions during harvesting on the overall biomass moisture content. In practical terms, it is the extrinsic moisture content that is of concern, as the intrinsic moisture content is usually only achieved, or applicable, under laboratory conditions.

Table 1 lists the typical (intrinsic) moisture contents of a range of biomass materials (McKendry 2002).

BIOMASS	MOISTURE CONTENT (%)	VOLATILE MATTER (%)	FIXED CARBON (%)	ASH CONTENT (%)	LOWEST HEATING VALUE (MJ/Kg)
WOOD	20	82	17	1	18.6
BAGASSE	16	59	21	4	17.3
BARLEY	30	46	18	6	16.1

STRAW					
LIGNITE	34	29	31	6	26.8
BITUMINOUS COAL	11	35	45	9	34

The parameters of interest that are affected by such contamination are the ash and alkali metal content of the material. Other factors aside, such as conversion to alcohol or gas/oil, the relationship between biomass moisture content and appropriate bio-conversion technology is essentially straight forward, in that thermal conversion requires low moisture content feedstock(Siwal, Sheoran et al. 2022).

Calorific value

The calorific value (CV) of a material is an expression of the energy content, or heat value, released when burnt in air. The CV is usually measured in terms of the energy content per unit mass, or volume; hence MJ/kg for solids, MJ/l for liquids, or MJ/Nm3 for gases(Beohar, Gupta et al. 2012).

The CV of a fuel can be expressed in two forms, the gross CV (GCV), or higher heating value (HHV) and the net CV (NCV), or lower heating value (LHV). The HHV is the total energy content released when the fuel is burnt in air, including the latent heat contained in the water vapor and therefore represents the maximum amount of energy spotentially recoverable from a given biomass source (McKendry 2002).

The actual amount of energy recovered will vary with the conversion technology, as will the form of that energy i.e. combustible gas, oil, steam, etc. In practical terms, the latent heat contained in the water vapor cannot be used effectively and therefore, the LHV is the appropriate value to use for the energy available for subsequent use.

Table 1 lists the CV of a range of biomass materials. When quoting a CV, the moisture content needs to be stated, as this reduces the available energy from the biomass. It appears normal practice to quote both the CV and crop yield on the basis of dry matter tones (dmt), which assumes zero percent moisture content. If any moisture is present, this reduces the CV proportional to the moisture content.

Proportions of fixed carbon and volatile matter.

Fuel analysis has been developed based on solid fuels, such as coal, which consists of chemical energy stored in two forms, fixed carbon and volatiles:

- The volatiles content, or volatile matter (VMs) of a solid fuel, is that portion driven-off as a gas (including moisture) by heating (to 950 "C for 7 min)
- The fixed carbon content (FC), is the mass remaining after the releases of volatiles, excluding the ash and moisture contents.

Laboratory tests are used to determine the VM and FC contents of the biomass fuel. Fuel analysis based upon the VM content, ash and moisture, with the FC determined by difference, is termed the proximate analysis of a fuel. Table 1 gives the proximate analyses of some typical biomass sources: values for lignite and coal are given for reference. Elemental analysis of a fuel, presented as C, N, H, O and S together with the ash content, is termed the ultimate analysis of a fuel... The significance of the VM and FC contents is that they provide a measure of the ease with which the biomass can be ignited and subsequently gasified, or oxidized, depending on how the biomass is to be utilized as an energy source (McKendry 2002).

This type of fuel analysis is of value for biological conversion processes only once the fuel is produced, enabling a comparison of different fuels to be undertaken. The significance of the O: C and H: C ratios on the CV of solid fuels can be illustrated using a Van Krevelen diagram (Fig. 1).

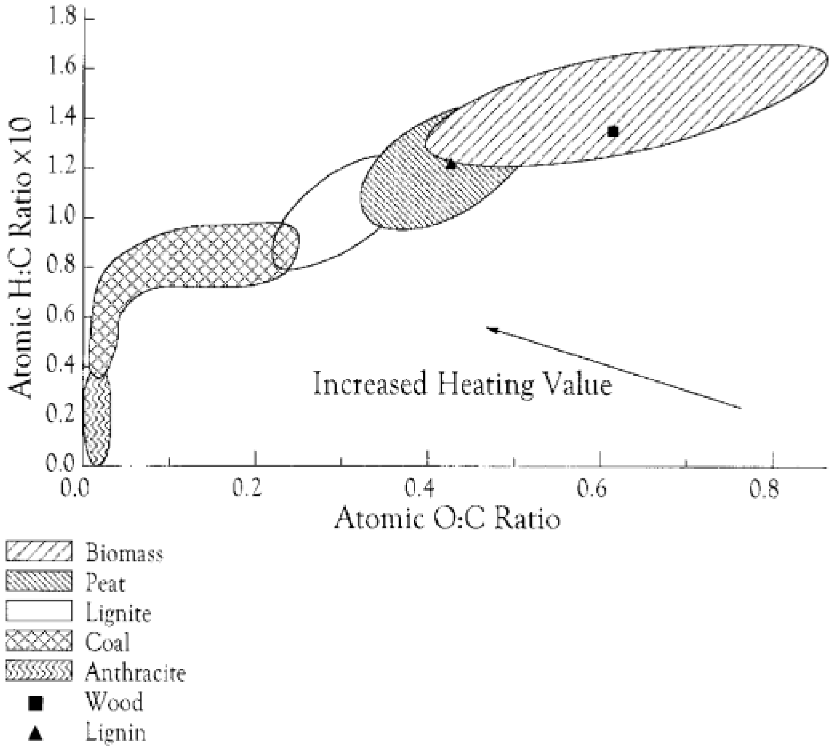

Fig 1: Van Krevelen diagram (Poudel, Karki et al. 2018)

Comparison of biofuels with fossil fuels, such as coal, shows clearly that the higher proportion of oxygen and hydrogen, compared with carbon, reduces the energy value of a fuel, due to the lower energy contained in carbon–oxygen and carbon–hydrogen bonds, than in carbon–carbon bonds(Van der Stelt, Gerhauser et al. 2011).

Ash/residue content

The chemical breakdown of a biomass fuel, by either thermo-chemical or bio-chemical processes, produces a solid residue. When produced by combustion in air, this solid residue is called ‘ash’ and forms a standard measurement parameter for solid and liquid fuels. The ash content of biomass affects both the handling and processing costs of the overall, biomass energy conversion cost(Korai, Mahar et al. 2017).

During biochemical conversion, the percentage of solid residue will be greater than the ash content formed during combustion of the same material. For a biochemical conversion process, the solid residue represents the quantity of non-biodegradable carbon present in the biomass.

This residue will be greater than the ash content because it represents the recalcitrant carbon which cannot be degraded further biologically but which could be burnt during thermo-chemical conversion (Zhang, Xu et al. 2010).

Dependent on the magnitude of the ash content, the available energy of the fuel is reduced proportionately. In a thermo-chemical conversion process, the chemical composition of the ash can present significant operational problems. This is especially true for combustion processes, where the ash can react to form a 'slag', a liquid phase formed at elevated temperatures, which can reduce plant throughput and result in increased operating costs(McKendry 2002).

An important characteristic of biomass materials is their bulk density, or volume, both as-produced and as-subsequently processed.

The importance of the as-produced, bulk density is in relation to transport and storage costs. The density of the processed product impacts on fuel storage requirements, the sizing of the materials handling system and how the material is likely to behave during subsequent thermo-chemical/biological processing as a fuel/feedstock(McKendry 2002).

2.2 CARBONIZATION OF BRIQUTTES

Direct use of agricultural residuals as fuel is normally characterized by low efficiency. Also the low bulk density of the residues often makes them uneconomical to store or transport. One method to overcome their difficulties is to density and carbonize them. The carbonized briquette develops a higher temperature in stoves and furnaces and has the advantages of relatively smokeless combustion. As it does not rot and it not attacked by termites, fungus, etc., the storage losses are relatively very low(Libra, Ro et al. 2011).

Unless burnt in controlled conditions, biomass-based fuels tend to produce appreciable quantities of smoke, problematic if the fuel is to be used in indoor environments. A common way to overcome this in briquetting is to carbonize either feedstock or the finished briquette(Agarwal 2007). Carbonization (or partial pyrolysis) drives off volatile compounds to leave more or less pure carbon; the bagasse is heated to within a critical temperature band (around 300℃) but with a restricted supply of air so that it does not ignite. Various processes options are available including simple earth kilns to more complex retorts that make use of the volatile compounds in heating the process (Ronsse, Nachenius et al. 2015).

As mentioned, the raw material used is sawdust from various species of tropical wood. The moisture content of these green or fresh sawdust varies from about 40-50%. The green sawdust are first screened to remove contaminants and oversized particles. They are then dried to a moisture content of about 8-10% in an impulse dryer with hot air that is generated using wood wastes. The fairly dry sawdust are then fed into a screw type briquetter for compaction into briquettes. The density of the briquettes formed is around 1200kg/m. The briquettes that leave the briquetting machine are hot and slightly roasted on the outside. As such they have to be left in the open to cool. The cooling process further enhances the binding between the sawdust particles (Ronsse, Nachenius et al. 2015).

The sawdust briquettes are then neatly arranged on a burgee which is an open cart with only 2 end walls, with air flow homes at the lower portion and rollers at its undersurface. The loaded bugees are then pushed into the carbonization kilns. After the bugee is pushed into place inside the kiln is then sealed(Jamison and Jamison 2014). The carbonization process is started by putting a few pieces of lighted briquettes on top of the pile before the bugee is pushed into the kiln. The sawdust briquettes are carbonized at a temperature of 850-875 degree for 108 hours with air flow that is controlled at various stages of the process. A good control of the air-flow is essential in ensuring that good quality charcoals are produced (Cao, Ro et al. 2013).

When the carbonization process is complete which is indicated by the emission from the chimneys becoming invisible, the bugess with the red hot charcoal inside are removed from the kilns and immediately covered with sealed boxes which are then completely sealed with sand to avoid any entry of air(Orge, McHenry et al. 2013).

2.3 BRIQUTTE BINDING AND FILLING MATERIALS

Biomass generally contain naturally occurring structural binders or stabilizing agents, such as lignin and proteins that are released and activated when biomass is densified at relatively high levels of temperature and pressure. This improves the structural particle bonding in biomass briquettes (Anukam, Berghel et al. 2021).

However, in some cases, the biomass may not contain significant amount of natural binder (lignin) or due to the densification conditions, additional binders may be required to achieve the desired briquette hardness and durability.

Briquette binders can be broadly divided into organic and inorganic binders. It could further be divided into organic, inorganic, and compound binders based on their composition (Anukam, Berghel et al. 2021).

The choice of binders among the various types is largely dependent on a number of factors, including The desired bonding strength, Low emissions, The effect on combustion performance of the briquette, Environmental friendliness, Sustainability and economic availability.

While binders are used to improve bonding between biomass particles during densification, actual mechanism of the bonding process is complex and yet to be fully comprehended.

Previous studies have propagated a number of theories to explain particle bonding in biomass densification including attraction forces between biomass particles, adhesion and cohesion forces, solid bridges and mechanical interlocking bonds, interfacial forces, and capillary pressure.

These theories have been approached from both mechanical and chemical point of views thus explaining the influence of biomass structural and chemical substances on the bonding process during densification.

2.3.1 Classification of Briquette Binder

As earlier mentioned, the three broad classes of briquette binders include organic, inorganic, and composite binders.

Organic binders generally have good binding properties, including high impact and abrasion strength, and high- water resistance. However, at high temperature, they decompose easily having poor thermal stability and mechanical strength(Claremboux and Kawatra 2022).

They are mostly characterized by Extensive availability, Low price, High heating value, Low ignition temperature.

There are four main types of organic binders and they include Biomass (agricultural wastes, forestry biomass, etc.), Tar pitch and petroleum bitumen (coal tar pitch, tar residues, etc.), Lignosul- phonate, Polymer binders (resins, polyvinyl, and starch) (Claremboux and Kawatra 2022).

Organic binders could further be divided into hydrophobic binders (e.g., asphalt, and coal tar) and hydrophilic binders (e.g., biomass) based on their reaction to water.

The poor thermal stability of organic binders has contributed in limiting their commercial application in biomass briquetting.

Inorganic binders have Strong adhesion, Non- pollution with sulfur capture characteristics, Low cost, good hydrophobicity. However, their combustion efficiency is lower due to their limited calorific values, and the ash content is often high. Examples are clay, bentonite, ammonium nitrate, etc. (Claremboux and Kawatra 2022).

Inorganic binder could be classified into three main types, Industrial (bentonite clay, cement, sodium silicate, and magnesium chloride), Civilian (limestone, and clay), Environmental protection (desulfurization agents, e.g., iron oxide, magnesium oxide, and calcium oxide) inorganic binders(Claremboux and Kawatra 2022)..

Compound binders comprise the combination of two or more binders with the aim of taking advantage of the multiple binding benefits offered by the different binders, thus yielding briquettes with high mechanical strength and thermal stability. Examples are starch and bentonite, molasses, and carbide lime(Utela, Storti et al. 2008).

2.3.2 Binder Selection

The choice of binders in biomass briquetting is often influenced by a number of factors, including: Availability, Cost, The raw material properties, Moisture content of the mix, the densification pressure, and the desired energy content of the briquettes.

2.3.3 Common Biomass Briquette Binders

As earlier stated, binders are added to biomass densification process in other to improve the compressive strength, abrasion resistance and, in some cases, the energy content of briquettes.

Different types of raw materials require different binder types due to their underlying material bonding mechanisms.

Glycerol Crude glycerin, a by- product in biodiesel production, has been successfully used as a binding agent in biomass briquetting with significant positive effects on the briquette properties. Although crude glycerin can be purified into valuable chemical for use in the pharmaceutical, food and cosmetics industries, the purification process is rather expensive and inefficient due to a wide variety of impurities it often contains. The glycerin market on the other hand is well saturated and its disposal at landfills is environmentally unsustainable. Thus, the price of glycerin has continued to decline making it economically attractive for use as a binder biomass briquette production. Glycerin has also been used in biomass pellet production. While the production of biomass briquettes with the addition of low quantity glycerol has shown desirable briquette qualities, high- quantity addition of the binder in sugarcane and sorghum residues briquettes up to 30 wt.% results in poor briquette quality, including high hygroscopic nature, low energetic value, and poor aesthetics and durability (Obi, Pecenka et al. 2022).

Starch

Starch is a white powder mostly extracted from various crops, including cereals, rhizomes, and roots, in the form of semi- crystalline granules which are unique to the individual crop source. The application of heat and water to starch brings about the formation of intermolecular hydrogen bonds between the two major polysaccharide components in starch amylose and amylopectin. This is achieved through the disruption of the granular structure of the starch molecules leading to swelling, hydration, and solubilization. This results in a viscous solution called starch paste that gels as it cools. The transition from granules to starch paste is accompanied by increased viscosity which increases the paste resistance to deformation showing significant binding strength. The high- energy content of starch in addition to its chemical and structural properties makes it an excellent binding agent in biomass densification and remains the most common biomass briquette binder in the literature (Ratnayake and Jackson 2008).

However, its use in commercial briquetting has been limited due to its high cost, low coking, and water- proof properties

Molasses

Molasses represents a low- cost liquid by- product discharged by the centrifuge in the last stage of extraction of sugar from cane or beets by means of repetitive crystallization. It is a thick non-transparent brown to dark brown high- density liquid fully soluble in hot and cold water. The carbohydrate content range from 48 to 53% and the water content lower than 25%. Molasses is often characterized by excellent stability and shelf life due to its high osmotic potential linked to its antimicrobial properties.

Furthermore, it is recognized as a cheap and environmentally safe promoter of bonding mechanisms among fine particles as it contains sucrose and gum (including starch).

The bonding property of molasses has traditionally been exploited in the feed industry for the preparation of compound feed, and only in recent decades has it found use in the bioenergy sector (Palmonari, Cavallini et al. 2020).

In general, the use of molasses as a binder in briquette production could significantly improve briquette combustion characteristics.

CHAPTER 3: MATERIALS AND METHODS

In this study sugarcane bagasse was used in formulating charcoal briquettes because of its availability in large quantities and at almost zero-cost, its negative environmental importance and the suitability of its energy parameters for the formulation of briquettes.

3.1. Materials

3.1.1 Raw materials

1. Bagasse and molasses were obtained from SUGAR COPERATION OF UGANDA LIMITED
2. Clay soil was obtained from Busabala swamp area
3. Calcium chloride was purchased
4. Tap water

3.1.2 Apparatus used

1. Oven
2. Bomb calorimeter
3. Platinum crucible
4. Bunsen burner
5. Porcelain motor
6. Tripod stand
7. Thermometer

3.1.3 Machinery

1. Brick built kiln

3.2 METHODOLOGY

3.2.1 Carbonization of bagasse

Bagasse is obtained and dried under sunlight so that to reduce moisture content. A dried sample is then weighed and its initial mass is obtained and then placed in an oven so as to further dry it and after so time, the bagasse is removed and reweighed to obtain its final mass.

Dried bagasse is then placed into a brick built kiln in order to carbonize it and obtain bio char. Bagasse is carbonized at different temperatures of 300^0C. 400^0C, 500^0C, 600^0C and 700^0C.

Figure 2 shows a brick-built kiln that was used to carbonize the dry bagasse.

1g of bio char was accurately weighed, crushed and placed in a platinum crucible with a lid which in turn is placed firmly on a tripod stand and heated at the bottom gently with the burner for about 2 minutes. Then after the gas adjusting screw was opened and so was the air control of the burner to full capacity and continued with heating until the small flame above the pinhole of the lead had ceased. The hot crucible was cooled using calcium chloride and weighed to obtain the final mass reading of the bio char.

3.2.2 Production of carbonized briquettes

Clay was obtained and large stone particles in it were handpicked and molasses were dissolved in water according to a ratio of 2:1

Bio char, clay and molasses were then mixed together manually using a spade and hoe according to different trials obtaining different briquettes depending on different ratios of molasses, bio char and molasses

Table 2 shows the carbonized bagasse and additives that were formulated using different ratios of carbonized bagasse, clay and molasses.

PARAMETER	MOLLASSES	CLAY	CARBONIZED BAGASSE	PRESSURE N/mm^2
Trial 1	1	2	20	0.25
Trial 2	1	2	20	0.50
Trial 3	1	2	20	0.75
Trial 4	1	2	20	1.00
Trial 5	1	1	40	0.25
Trial 6	1	1	40	0.50
Trial 7	1	1	40	0.75
Trial 8	1	1	40	1.00

Briquettes were produced using ratios of 1:2:20 and 1:1:40 for molasses, clay and carbonized bagasse respectively. The ratio of different components were arrived at after several pre-trials and the briquettes produced tested for various parameters and burning characteristics. The pre-trial results indicated that the lower the proportion of clay, the better the performance of the briquettes.

A range of 0.25, 0.50, 0.75 and 1.00 N/mm2 pressure was applied using a piston press. For each trial, a replica of four sample briquettes were produced using a combination of different ratios and pressure.

The thoroughly blended components in various ratios were compressed into cylindrical briquettes measuring 14 mm diameter and lengths not exceeding 150 mm. The pressing was carried out using a universal strength testing machine with 500 KN capacity at various pressures and loading rates.

3.2.3 Analysis of Physico Chemical parameters

3.2.3.1 Moisture Content

The percentage moisture content (PMC) was determined by weighing 1.5g of the briquette sample in a crucible of known mass and placed in an oven set at 105°C ± 5°C for 1 hour. The crucible and its content were removed from the oven allowed to cool to room temperature and reweighed. This process was repeated until the weight after cooling became constant and the value was recorded as the final weigh W_2. This process was repeated for different samples of the briquettes and results are tabulated in Table 3. The sample's moisture content was determined using equation 3.1

$$PMC = \frac{W_1 - W_2}{W_2} \times 100\% \qquad (3.1)$$

3.2.3.2 Ash Content

1.5g of the briquettes samples was placed in a closed furnace and burnt completely. The weight of the residue was taken with an electronic balance and recorded as W_3. This process was repeated for different samples of the briquettes and results are tabulated in Table 4.The percentage weight of residue gives the ash contained in the sample and its determined using the equation 3.2

$$PAC = \frac{W_3}{W_2} \times 100\% \qquad (3.2)$$

3.2.3.3 Volatile Matter

The percentage volatile matter (PVM) was determined by placing 1.5g of the briquettes sample in a crucible and kept in a furnace for 8 minutes, at temperature of 550^{o}C ± 5°C and weighted after cooling. This process was repeated for different samples of the briquettes and results are tabulated in Table 5. The percentage volatile matter of the sample was determined using equation 3.3

$$PVC = \frac{W_2 - W_4}{W_4} \times 100\% \qquad (3.3)$$

3.2.3.4 Fixed carbon

The percentage fixed carbon (PFC) is given by equation 3.4 and the results for different briquette samples were recorded in table 6

$$PFC = 100\% - (PAC + PMC + PVM) \qquad (3.4)$$

3.2.3.5 Calorific Value

The calorific value of the briquettes were determined using a bomb calorimeter. 1.5g of the briquettes sample was burnt completely in oxides of oxygen. The liberated heat was absorbed by the water and calorimeter. The heat lost by burning briquette was the heat gained by water and calorimeter thus the initial temperature t_1 and final temperature t_2 were determined and recorded. The calorific value (CV) of the different samples of the fuel was calculated from the measured data from(Inegbedion) using equation 3.5 below and results are tabulated in Table 8.

$$CV = \frac{(BF \times \Delta t) - 2.3l}{W} \qquad (3.5)$$

Where BF is the Burn Factor = 336.734m

$$\Delta t = t_2 - t_1 \tag{3.6}$$

W is the weight of the fuel used

L is the length of the wire.

CHAPTER 4: RESULTS AND DISCUSSIONS

4.1 Results

4.1.1 Formulation of charcoal briquettes

Bagasse, clay, and molasses were the main ingredients used to make briquettes. It was discovered that 5 bags of raw bagasse were required for every 1 bag of carbonized bagasse during the carbonization process. According to this, if Five tons of raw bagasse must be processed into one ton of charcoal briquettes used. An estimated 1.6 million tons of bagasse are produced in Kenya each year, hence translates to a potential annual production of 288,000 tons of charcoal briquettes based on a 5:1 raw-to-carbonized bagasse ratio and the assumption that 90% was applied yearly. This equates to around 8.3 million bags of 35 kg apiece. Annual production of carbonized bagasse-based charcoal briquettes. As Kenya utilizes approximately 2.4 million tons each year of charcoal made from sources rooted in forests, Bagasse-based charcoal briquettes would improve environmental preservation and protection while easing pressure on deforestation.

Fig 3: samples of carbonized briquettes from bagasse.

4.1.2 Physico Chemical Properties of Carbonized Briquettes tables

Table 3: Percentage Moisture Content of Various Briquettes

EXPERIMENT NO.	W_1	W_2	PMC
TRIAL 1	1.49	1.431	4.1%
TRIAL 2	1.49	1.431	4.1%
TRIAL 3	1.49	1.426	4.5%
TRIAL 4	1.49	1.423	4.7%
TRIAL 5	1.49	1.429	4.3%
TRIAL 6	1.49	1.431	4.1%

TRIAL 7	1.49	1.431	4.1%
TRIAL 8	1.49	1.412	5.5%

Table 4: Percentage Ash Content of various briquettes

EXPERIMENT NO.	W_2	W_3	PAC
TRIAL 1	1.431	0.758	51.3%
TRIAL 2	1.431	0.738	51.6%
TRIAL 3	1.426	0.670	47.0%
TRIAL 4	1.423	0.596	41.9%
TRIAL 5	1.429	0.573	40.1%
TRIAL 6	1.431	0.521	36.4%
TRIAL 7	1.431	0.578	40.4%
TRIAL 8	1.412	0.569	40.3%

Table 5: Percentage Volatile Matter of briquettes

EXPERIMENT NO.	W_2	W_4	PVM
TRIAL 1	1.431	1.163	23.0%
TRIAL 2	1.431	1.168	22.5%
TRIAL 3	1.426	1.150	24.0%
TRIAL 4	1.423	1.136	25.3%
TRIAL 5	1.429	1.157	23.5%
TRIAL 6	1.431	1.125	27.2%
TRIAL 7	1.431	1.155	23.9%

TRIAL 8	1.412	1.133	24.6%

Table 6: Effect of carbonization temperature on the yield of bio char

Carbonization Temperature(^{0}C)	Percentage Fixed Carbon
300	43
400	55
500	64
600	68
700	70

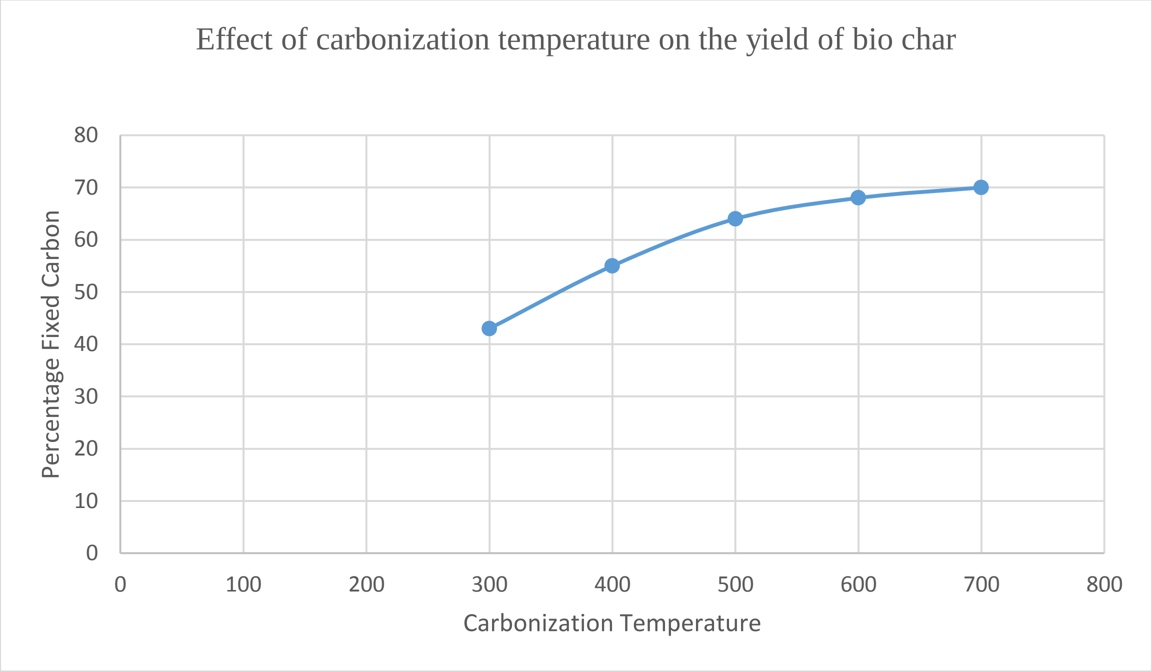

Table 7: Percentage Fixed Carbon of Briquettes

EXPERIMENT NO.	PAC	PVM	PFC
TRIAL 1	51.3%	23.0%	25.7%
TRIAL 2	51.6%	22.5%	25.9%
TRIAL 3	47.0%	24.0%	29.0%
TRIAL 4	41.9%	25.3%	28.0%
TRIAL 5	40.1%	23.5%	36.4%
TRIAL 6	36.4%	27.2%	36.4%

TRIAL 7	40.4%	23.9%	35.7%
TRIAL 8	40.3%	24.6%	35.1%

Table 8: Calorific Value of the Briquettes

PARAMETER	MOLLASSES	CLAY	CARBONIZED BAGASSE	PRESSURE N/mm^2	Calorific Value (Kcal/g)
Trial 1	1	2	20	0.25	2.684
Trial 2	1	2	20	0.50	3.093
Trial 3	1	2	20	0.75	3.338
Trial 4	1	2	20	1.00	3.420
Trial 5	1	1	40	0.25	3.420
Trial 6	1	1	40	0.50	4.105
Trial 7	1	1	40	0.75	4.390
Trial 8	1	1	40	1.00	4.053

4.2 Discussion

4.2.1 Moisture Content

The average moisture content of the briquettes was 4.7 % for the 1: 2: 20 formulation while it was 4.2 % for the 1: 1: 40 formulation with minimum and maximum moisture content of 4.1 % and 4.7 % respectively. Physico-chemical properties of clay that was used as a binder in the formulation of bagasse briquettes was 2.8 % at moisture content less than 10%.

When a substance has a moisture level below 18%, it no longer contains free water but rather bound water, which is water that has chemically linked to the material. This suggests that the majority of a material's physico-chemical properties would not be affected by moisture content as long as it has a moisture content of less than 18%.

However, it was crucial to examine the different characteristics of charcoal briquettes at essentially equivalent moisture content levels. The SABS (2000) advises analyzing these parameters on charcoal briquettes intended for residential use when the moisture level is no higher than 10%.

4.2.2 Ash content

The briquettes made with the 1: 2: 20 formulation had an average minimum and maximum ash content of 46.5% and 51.6%, whereas the briquettes made with the 1: 1: 40 formulation of molasses, clay, and carbonized bagasse had an average minimum and maximum ash content of 36.4% and 40.4%, respectively. An extremely high proportion of ash content 90.1% was discovered in clay.

At all pressures, the 1: 2: 20 formulation had a larger percentage of ash content than the 1: 1: 40 formulation. This was due to the fact that the earlier formulation had a higher proportion of clay than the later version. A formulation that contained less clay resulted in briquettes that emitted less ash, which improved the briquettes' quality.

When compared to other forms of charcoal, wood charcoal's 1.9% ash content bagasse coal (36.4%). Lower ash concentration in charcoal is useful since it reduces handling and disposal expenses after the burn.

The fact that charcoal has been employed economically for a variety of purposes is advantageous for handling charcoal after usage.

4.2.3 Volatile Matter

When molasses, clay, and carbonized bagasse were combined in the ratio of 1: 2: 20, the average volatile matter of the briquettes formed was 23.7%, ranging from a minimum of 22.5% at 0.50 N/mm2 pressure to a maximum of 25.5% at 1.00 N/mm2 pressure. The briquettes made with the 1: 1: 40 formulation had an average volatile matter somewhat higher at 24.1%. This was due to the fact that the 1: 1: 40 formulation contained more carbonized bagasse than the 1: 2: 20 formulation. For this formulation, the minimum and highest volatile matter contents were 23.5% and 25.8%, respectively. This contrasted quite favorably with wood charcoal, which had a 24.8% yield. The amount of volatile matter complied with SABS's (2000) recommendation that it not exceed 27%.

It was discovered that there was not much variance between average values of the briquettes made using the same formulation under various pressures. The average values for clay and charcoal briquettes, however, varied greatly. Clay's average contribution to volatile matter was just 5.7%, whereas the volatility of charcoal varied from a low of 22.5% to a maximum of 27.2%. Because clay is known to have a small amount of organic matter but mostly inorganic particles, the minimal proportion of volatile matter in clay was anticipated. The high percentage of organic matter in the substance was thought to be the cause of the high amount of volatile matter.

4.2.4 Fixed Carbon

For the two formulas, the resulting briquettes' fixed carbon content roughly matched one another. The minimum and maximum values for the 1: 1: 40 formulation were higher, at 35.7% and 37.8%, respectively. The briquettes' minimum and highest fixed carbon contents for the 1: 2: 20 formulation were 25.7% and 29.0%, respectively. The fixed carbon content of the wood charcoal was much higher than that of the briquettes, at 73.3%, more than twice as high.

Due to its extremely low fixed content (7.1%), clay tends to increase cooking time through a slower rate of heat release (bake-oven effect). It also had a fuel-saving effect, which reduced the briquettes' calorific energy. The charcoal produced is better when the fixed carbon content is higher since the related calorific energy is typically high.

4.2.5 Calorific Value

For the 1: 2: 20 formulation, the calorific energy of the briquettes, which is heat of combustion and a potent predictor of a biofuel's superiority, varied between a minimum of 2.684 Kcal/g and a maximum of 3.420 Kcal/g. They had equivalent values of 4.053 Kcal/g and 4.390 Kcal/g for the 1:1:40 formulation. Briquettes piston-pressed at a pressure of 0.50 N/mm2 had the maximum calorific energy in each of the formulations.

Clay made a significant contribution to the production of combustion heat, with a calorific energy of 0.619 Kcal/g. The disparities between the calorific values of bagasse as a biomass residue and those of clay and bagasse that have been carbonized to create charcoal briquettes. Despite the former's calorific energy is 5.04 Kcal/g, whereas at its greatest it was just 4.390 Kcal/g. due to the latter. This was in accordance with its low heat release property in the technique that lowers the briquettes' calorific content.

At all pressure levels, it was discovered that the calorific energy values of the charcoal briquettes made with the 1: 1: 40 formulation of molasses, clay, and carbonized bagasse were higher than those made with the 1: 2: 20 formulation. This was due to the 1: 1: 40 formulation using less clay than the 1: 2: 20 formulation. Overall, the bake-oven effect and the fuel-saving impact of clay helped make charcoal briquettes suitable for use in homes, especially for cooking and heating.

CONCLUSION

The most suitable parameters that produced briquettes which complied with current charcoal specifications for household use were in the ratio of 1:1:40 for molasses, clay and carbonized bagasse respectively at 0.50N/mm2 pressure. At this formulation, briquettes were produced whose ash content, volatile matter and calorific energy were 36.4%, 27.2% and 4.390 Kcal/g respectively.

The briquettes produced should burnt without sparks and smokeless, producing no irritating smell. They ignited easily and took relatively long before they extinguished. They are therefore recommended for household use in Uganda.

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