**Briquettes: Energy Sustainability and Environmental Conservation**

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**Abstract**

The use of clean and affordable energy source is significant to improving human health, lowering the negative impact of fossil fuel energy consumption and saving terrestrial lives. The use of firewood as a form of fuel in most developing countries is synonymous to desertification. The study encompasses distribution of research articles across municipal solid waste, agro-waste, faecal sludge, coal and bio-coal, and sludge in revealing trends in the development of briquettes, a domestic energy source. The review suggests that thermal energy performance indicators for briquettes are a function of its feedstock composition, with multi-feedstock briquettes exhibiting superior thermal performance. Briquettes were found to established good potentials for household energy utilization in terms of cleanliness, affordability, minimum emissions and economic viability. The work recommends the establishment of energy conversion centers for briquettes production with aftermath effects of job creation, environmental and energy sustainability.

**Key words:** Briquettes, wastes, environmental cleanliness, energy sustainability, economic                     viability.

**INTRODUCTION**

The various activities involved in the exploration of fossil fuels for production of liquefied petroleum gas, LPG as a household energy source often are linked to environmental degradation, besides the increasing its energy cost. The practice of alternative energy source from the burning of wood as household fuel is mostly found in developing countries as a result of the non-affordability and or scarcity of kerosene. This has considerably increased the rate at which the forests tress and its other resources including other economic tress are daily utilized as source of household fuel. This approach increases and removes the submersion of carbon dioxide in the environment promoting global warming. Municipal Solid Waste, MSW are debris generated by human activities within the households, government institutions such as educational, offices, hospitals; local markets, etc. Urban and semi-urban areas with inadequate sanitation facilities to handle these waste experienced some health challenges sometimes leading to outbreak of diseases that claim lives. Large quantities of agricultural waste on the farms are left uncollected none converted to fuels especially in developing countries (Benjamin, 2011**)**. It is noted that large quantities of agricultural waste are left on the farms uncollected and unconverted especially in developing nations. These wastes sometimes pollute nearby water bodies during the wet season. Numerous advantages are accrued to the production and utilization of briquettes from various materials as a solid form of fuel. These include its affordability as a source of fuel for domestic homes, aid in preserving forest resources and employment opportunities as well as obtaining a clean environment. Briquettes on the other hand is said to be a lump of a designed shape of a mechanically compacted material made from coal or by-coal product, biomass or charcoal dust often used as fuel to ignite and maintain fire. Usually, the briquetting process aims significantly on the production of smokeless solid fuels made from coal, municipal solid waste, faecal sludge, sludge, and agro-wastes. Some briquetting methods involved the compression of the materials without addition of adhesives known as binders. However, the inclusion of binders assists in the cohesiveness of the material (Mangena and Cann, 2007). Briquettes moisture content which is the material water retentive capacity known to affect the material strength and density. Lower moisture content of briquettes is preferable, while compressive strength is linked with low moisture content. Good compactions of the pellets are required to overcome shattering (Julio *et al.,* 2021). Briquettes durability/abrasive resistance is afunction ofits density and durability. The test of durability describes the production of fine powders when the briquette is subjected to mechanical handling (Jasbir, 2022). It is recommended that briquettes should possess high density that can be translated into its durability, energy content and combustion speed as this feature is significant in easing the transportation. Furthermore, calorific value of briquettes is sometimes affected by its binder as they are known to reduce the value (John *et al.,* 2018). Thus, the appropriate selection of a binder is instrumental to briquettes formation. This work review the potential of briquettes as a solid energy fuel made from municipal solid waste, faecal sludge, agro-waste, sludge, coal and bio-coal.

**METHODOLOGY**

The review focuses on research works centered on the conversions of agro-waste, municipal solid waste, waste from faecal sludge, sludge and coal and bio-coal into briquettes as energy source. Municipal solid wastes, faecal sludge and sludge are readily available in semi-urban and urban centers plays significant role in the production of briquettes, while agro-waste mostly found on farms after the harvest season and or agricultural processing activity constitute a tangible source of feedstock for the production of briquettes. The availability of coal which in some cases is use in combination with agro-waste has proven to be less hazardous with improved thermal combustion characteristics. An extensive range of research works involving various materials and binders for briquettes formation, experimentation and results obtained are reviewed and presented with conclusions drawn.

**Municipal solid waste and briquettes production**

Municipal solid waste consist of less valued items that are discarded from homes, educational institutions, offices, hospitals, shopping malls, markets, etc and include product packaging, bottles, clothes, food remnants, appliances etc. Pete and Smail (2003) assessed the socio-economic risks and the overall sustainability of manufacturing fuels from Municipal Solid Waste in Rwanda. The work proposed an expansion in briquette production in Kigali would achieve significant environmental and socio-economic benefits through the production and sale of 15,000 tonnes of briquettes per year creating 450 jobs and supporting indirectly a further 1,550 jobs with savings of about 86,000 m3 of fuel-wood. Anita and Ramesh (2011) experimentally produced and analyzed briquettes by screw extrusion method, piston press approach. Addition of waste plastic materials improved the fuel quality. Test performance was in-line with Japanese Industrial Standards. Tri and Lalu (2012) experimentally analyzed properties of produced briquette from Municipal Solid Waste, MSW. Test results indicated the waste could serve satisfactorily as solid fuel. Norbert *et al.,* (2020) collected samples of Municipal Solid Waste (MSW) produced briquettes from several companies with unknown characterization. Physical and chemical properties analysis of developed briquettes as well as comparison for energy cost to that of charcoal and peat were conducted. Findings indicated that briquettes made from MSW has lower unit price compared to charcoal and that of peat. Richard *et al.,* (2020) examined heavy metal concentration in the Municipal Solid Waste, MSW in Kampala City, Uganda as well as the physicochemical properties of briquettes produced in comparison to those of charcoal. Municipal solid waste, MSW calorific values of briquettes were slightly lower compared to that of charcoal, and heavy metal concentrations in collected bio-waste below the permissible acceptable limits. Bayu *et al.,* (2020) dried, carbonized, crushed and sieved degradable municipal waste for briquettes production. Test parameters of density, porosity weight index, shatter resistance, moisture content, volatile matter, ash content, fixed carbon content, and caloric value investigated show similarity to those reported in literature. Vaidhegi *et al.,* (2022) examined the production of green briquettes for commercial use in combination with wood industry residues using extract of water hyacinth plant as the natural binding agent using wastes collected from households and wood processing industries. The work concluded that briquetting technology using MSW, saw dust and natural binding agent is best way to effectively reusing waste as energy. Jasbir (2022) looked into the possibility of producing non-carbonized fuel briquettes from locally available municipal solid waste in comparison to usage of regular food waste. Performance evaluation result indicates briquettes made from decomposed food waste had a higher bulk density, net calorific value but a lower burning rate. Eminet *et al.,* (2023) utilized municipal solid waste in combination with avocados and mangoes leaves for briquettes production using paper as a binder. Result variables of moisture, volatile matter, fixed carbon, ash content, calorific value, burning rate, burning time and ignition time indicated favorably result as a household solid energy source. Charles *et al.,* (2023) assessed energy production from organic fraction of municipal solid waste in Nigeria through adoption of qualitative and quantitative methods. The estimates show that about 1.82 million tons of solid fuel amounting to 8.6 million MWh/year could be obtained through drying and densification annually in the country.



Plate I: Fuel pellets from municipal solid waste

**Faecal sludge as a form of energy**

Faecal sludge is the raw or partially digested mixture of excreta and water, usually accumulated in containment such as single pits, septic tanks or other on-site sanitation systems. Bogdan and Andrzej (2016) presented sewage sludge with coal briquettes as a fuel for combustion process. Obtained results showed possibility of briquetting of municipal sewage sludge with coal in roll presses, equipped with asymmetric thickening gravity feed system. Physical and chemical analysis of prepared briquettes confirmed that briquettes have good fuel properties to combustion process. Nita *et al.,* (2017) evaluated the quality of bio-charcoal briquette with materials from leather cassava tubers and sludge from wastewater treatment plant. Resultant briquette quality based on compressive strength and bio-charcoal carbonation ash content were within acceptable limits. John *et al.,* (2018) tested the performance of fecal sludge-saw dust bio-fuel briquettes in three commonly used cook stoves in Kenyan. The fuel had good characteristics of specific fuel consumption, thermal efficiency, burning rate, boiling rate as well as emissions for carbon (iv) oxide and carbon monoxide. Yvonne (2019) in his project sponsored by water research commission cooperation and UNICEF in Finland concluded that there is an opportunity for reusing faecal sludge as a fuel source in the form of briquettes. Irvan *et al.,* (2021) purposefully converted slack waste into charcoal briquettes by adding polyacrylamide as adhesives. The results clearly gave significantly improved optimum briquettes values of heating value, moisture content, density, and length of combustion over previous empirical researches. Bontu (2021) studied the physicochemical characterizations of brewery spent grains, brewery waste-water sludge, sawdust, carbonized mixed samples, carbonized mixed briquette, non-carbonized mixed briquette, and results compared to sawdust briquettes. Proximate and ultimate analysis indicated that brewery spent grains and brewery wastewater sludge could serve as a replacement for household energy use. Olivier *et al.,* (2023) collected faecal sludge from households for briquettes formation. The process involved sludge characterization, drying, sorting, carbonization, milling, and briquetting. Findings for zinc, cadmium, and lead were within the acceptable limits for the Tanzanian Standards. However, the addition of 25% sawdust or charcoal dust improves both the gross and net calorific values of the briquettes with emission reduction for particulate matter and carbon monoxide.

 

Plate II:Briquettes from faecal sludge(https://sanihubwaterforpeople.wordpress.com)

**Agro-waste and briquettes formation**

Agro-waste is a term used to describe residues of plant originating from arable land and horticulture. Examples include rice husk, wheat straws, maize straw, etc. Oyedemi (2012) briquetted sawdust and maize cob particles of 0.6 mm fine and 1.18 mm coarse particles with Cissus populnea gum concentrations of 1-30 % (w/w) and pressure levels of 1.5- 5.0MPa. Test performance using a briquette stove indicated a maximum thermal efficiency of 38.0 %. Gmelina arborea sawdust briquettes were stronger and more durable but less efficient in combustion than maize cob briquettes. Cissus populnea gum was found to be more suitable for the production of the briquettes. Stephen *et al.* (2013) reported the findings of densifying grind maize cobs and Ceiba pentandra sawdust at room temperature using low compacting pressure without a binder. Particle sizes of C. pentandra and maize cobs and ≤1 mm and in the mixing percentages of 90:10, 70:30 and 50:50. Evaluation from test performance of produced briquettes shows that adequate physical and mechanical characteristics could be produced from maize cobs at room temperature using low compacting pressure. Abdu and Sadiq (2014) carbonized and characterized four different briquettes charcoal grades obtained from corn cobs using locally sourced tapioca starch as binder. The briquette charcoal has a mean calorific significantly higher than those of bagasse and wood charcoal. Vyas *et al.,* (2015) undertook a study to evaluate the properties that influence briquettes storage and combustion properties using varieties of biomass feedstock. No influence by relative humidity was found at temperature between 25 to 37ºC, whilst periods of high humidity neither affect storage of briquettes. Ndindeng *et al.,* (2015) optimized briquettes made from rice milling by products using different combinations of raw materials feedstock and methods. Characteristics of husk-bran-palm press fiber and husk-bran briquettes provided best option in terms of hardness, start-up time, specific fuel consumption and flame temperature. Harshita *et al.* (2015) adopted an experimental research for six biomasses of charcoal dust, saw dust, rice husk, dry leaves, wood chips, groundnut shells and two binders of cow dung and starch. Subjective evaluation of physical properties of texture, cohesiveness, moisture, shape, evenness of surface and appearance of surface indicated that briquettes made from charcoal dust and other biomass materials with starch combinations were found to be optimum, whereas briquettes made from charcoal dust and other biomass materials with cow dung combinations gave maximum values for calorific value. Musa A. Jatto (2015) gave an overview of the different types of energy generation using biomass sources, focusing on the challenges and implications of rice husk for the Nigerian society. The study concluded that briquettes produced from rice husk residue gives good substitutes as well as good supplement to firewood energy source. Orhevba *et al.,* (2016) presented the result of preliminary synthesis and characterization of composite biomass briquettes produced from different ratio of rice husk and maize cob using starch as binder. Composite briquettes of rice husk and maize cob demonstrated good properties progression as a source of solid fuel. Suryaningsih, *et al.,* (2017) characterized and analyzed physical-chemical properties, calorific value, water content and fixed carbon content of briquettes made from coconut husks, sawdust, rice husks, coffee husks and results compared with charcoal and coal. Assessment of experimental results pinpoint that bio briquettes of coconut husks had the highest calorific value. Modestus *et al.,* (2018) obtained briquettes from the combination of sawdust and groundnut shell, while utilizing starch and condemn oil as binder. Optimization technique predicted combustion related properties of the briquette at the optimum level having density of (277.9 kg/m3, ash content of 25.29%, moisture content of 4.68 %wt, bulk density of 3.03 g/cm3 and burning rate of 0.46 g/min. Dewe and John (2018) aimed at increasing the calorific value of rice husk briquette by making organic briquettes from mixtures of rice husk charcoal and coconut shell charcoal by using the blending method. Proximate analysis of the briquettes in term of moisture content, ash content, volatile matter content and calorific value met the quality standard of briquette fuel according to Indonesian National Standard. Rafael *et al.,* (2019) presented the production and energetic characterization of briquettes produced from cotton wastes and sawdust residues under dissimilar formulations for comparison purposes. Biomass characterization was performed by apparent density, immediate analysis, calorific value and mechanical resistance of briquettes. Cotton waste had good mechanical and physical chemical characteristics. Phyu *et al.,* (2019) prepared and characterized briquettes of coconut husks origin having two varying sizes and lengths. Coconut husks were densified using potato starch as binding agent by through a manual briquetting machine. Physical and combustion characteristics of test results proved that coconut husks briquettes are superior comparable to firewood charcoal. Gutu and Duresa (2020) carbonized, crushed, grind and estimated the calorific value of five varieties of briquettes prepared from corn cob employing standard methods. The calorific value for the most favorable higher heating value was 29.67 MJ/Kg. Andrés *et al.,* (2020) studied the influence on the mechanical properties of briquettes obtained from the mixture rice husk and pine sawdust biomasses through a mixed factorial experimental design. Tests clearly show that the mechanical durability met the German Institute for Standardization. Gati *et al.,* (2021) described the effect of the composition of coconut shell charcoal and durian skin, molasses adhesive and starch on the characteristics of bio briquettes through proximate analysis. The bio briquettes were analyzed for moisture content, ash content, volatile matter, fixed carbon content, burn time, calorific value, morphology as well as proximate analysis which gave values comparatively to that of coal. Anwar *et al.,* (2021) investigated the effect of initial moisture contents of 12%, 14%, and 16% of rice husk-based briquettes blended with 10 wt% of kraft lignin on their chemical and physical characteristics. The briquette properties were evaluated by performing chemical and physical analyses. Durability values of all briquette samples met required standard with good compressive strength, surface morphology, and acceptable density range. Jamilu *et al.,* (2021) characterized physical properties of briquettes prepared from rice husk and coconut shell in varying ratios. Experimental and predicted values for calorific values, density and moisture content demonstrated good agreement with those of the American Standard of Testing Materials and those reported in literature. Efri *et al.,* (2022) presented a bio briquette as environmentally friendly alternative energy source from palm kernel shells and coconut shells by determining the optimum mass ratio. The results of the quality analysis have shown that all samples met all the Indonesia National Standard for bio-briquette. Marcus *et al.,* (2022) effectively utilized coconut shells and corncobs for briquettes production with diverse binders. The study revealed that coconut shell briquette generates more heat, higher calorific value and better resistance to water penetration then those of corncobs, whilst corncobs briquette gave higher percentage of ash content. Teeraya *et al.,* (2022) investigated the properties of sugarcane bagasse fuel pellets treated by dry and wet torrefaction and evaluated its economic viability. Wet torrefaction could reduce the ash content by 1% at a torrefaction temperature above 180°C resulting in higher quality and more marketable fuel pellets. Ariani *et al.,* (2022) utilized pineapple peels for bio-briquette production using variations in the composition of sewage sludge, pineapple peels, and used rejected papaya, cow dung, and starch as the adhesives. Optimum briquettes were obtained from 0:90:10 compositions of 0% sludge, 90% peel, and 10% starch. Bill *et al.,* (2022) analyzed the economic viability of cooking biomass briquettes made from coconut shells, rattan waste, banana peels, and sugarcane bagasse. A life cycle cost method and sensitivity analysis based on a 10-year lifetime were applied to a typical Cameroonian household with an annual cooking energy requirement of 950 kWh. Briquettes coconut shells had the minimum life cycle cost, those from banana peels had the highest cost, while fuel-wood replacement gave maximum present value of net benefit and wood charcoal been the cheapest. Michael *et al.,* (2022) designed, produced and evaluated two types of cooking stoves using alternative fuels produced from sawdust, wood shavings and rice husk as briquettes. Weight of briquette burnt, char produced, fuel consumption rate, thermal efficiency, power input and output as well as the specific fuel consumption were evaluated. In both stoves, sawdust briquette had the highest power output with rice husk briquette having the least. Abreham *et al.,* (2022) compared the use of a natural resin and starch as a binder for the production of fuel briquette from solid waste biomass. Proximate analyses show comparatively similar characteristics for properties of the briquettes. Mega *et al.,* (2023) evaluated the features of rice husk charcoal briquettes with variations in compacting pressure. Combustion rate obtained shows that briquettes with lower compaction pressure had higher combustion rate than those higher compaction pressure. Toran and Sindhu (2023) in an attempt to evaluate the energy consumption and economic viability of biomass briquettes, produced briquettes from rice husk and rice straw. Caloric value of produced briquettes gave were within an acceptable range.

 

Plate III: Ground nut shell and rice husk briquettes (L-R)

**Sludge as a source of energy**

Sludge is a viscous thick, soft and wet mixture consisting of liquid and solid components especially the product of an industrial or refining process. Stéphanie *et al.,* (2015) explored an inadequate final disposal of sludge as a sustainable alternative for energy production and utilization by producing briquettes using dry sludge from a Sewage Treatment Plant in Brazil. Vegetable oil served as thicken for briquettes and comparison made to 20 eucalyptus charcoal in terms of calorific potential. Calorific potential of charcoal obtained was 16.66 22 MJ/kg, while that of briquette reached 12.94 MJ/kg, with higher density for briquettes from sludge than that of charcoal. Ing–Jia and I–Tsung (2016) proposed an optimal formula for producing bio-fuel briquettes from industrial sludge. Experimental results demonstrated that food processing sludge and sewage sludge can offer excellent calorific value, combustion rate and flame temperature, while pulp sludge and sewage sludge could provide cementing properties. Imeh *et al.,* (2017) investigated the development and characterization of biomass briquettes from tannery solid wastes (TSWs) in Kano. Scanning electron microscopy and proximate analysis were carried out on samples and properties of thermal efficiency, durability and compressive strength determined. Calorific value, durability and energy value of briquettes developed comparable favorably to other fuel sources such as sub-bituminous coal. Nusong and Puajindanetr (2018) utilized industrial wastes from wastewater sludge of a beer industry and biodiesel production wastes for briquettes production. Results show that appropriate ratio of brewery wastewater sludge and bleaching earth by weight of 95:5 provided the highest heating value. Kuma *et al.,* (2019) produced fuel briquettes from sludge waste at Dire Dawa Ethiopia according to ASTM procedure. Mean average value for fixed carbon content and calorific value were 39.268% and 4143.269 cal/g respectively. Manyuchi *et al.,* (2019) made charcoal briquettes from brewery waste by shedding spent brewery grains to particle size range of 2-10 mm and then briquetted at 2 MPa at a 1-minute compaction periods to square biomass briquettes. Charcoal briquettes formed had optimum calorific value obtained at 400 °C. Julio *et al.,* (2021) determined the technical feasibility of the barbecue charcoal production using briquettes produced with different blends containing sludge from poultry abattoir and Pinus spp. shavings. Results showed the compressive resistance, gross calorific value, volatile matter, and fixed carbon content (FC) of charcoals having a decreasing trend as the proportion of sludge increases in the blends whilst the charcoals’ bulk density increased, which also increased its energy density and ash content. The optimum blend for household charcoal production was that of 90% sludge and 10 % Pinus spp. shavings.



Plate IV: Briquettes from sludge mixed with water hyacinth

**Coal and bio-coal briquettes**

A bio-coal briquette is a solid fuel source resulting from the combination of usually a low rank coal, an agricultural biomass material, a binder, sulphur fixation agent, and any other supplementary additives that may be added. Ogbuagu *et al.,* (2013) produced briquettes from coal and rice husk by blending varying compositions of coal and rice husk using calcium sulphate as a binder and calcium hydroxide as the desulphurizing agent. Proximate analysis showed that briquettes composition of 60% coal and 40% rice husk exhibited optimum combustible quality when compared with other compositions of briquettes. Ikelle and Mbam (2014) presented the study and production of the properties of smokeless briquettes of various compositions with coal and rice husk using starch, bitumen and CaSO4 as the binders, while Ca(OH2) was the desulphurizing agent. Prepared briquettes were sun dried for seven days, subjected to various tests to assess fuel quality. Briquettes with starch as binder had better results for ignition time, lower sulphur emissions, higher calorific values and longer burning time for all compositions. Gholipour *et al.,* (2014) investigated physical and chemical properties of briquettes of bituminous coal and sawdust/beet pulp. Physical stability of sawdust briquettes was studied by water resistance index and compressive strength considering the effect of moisture, composition and pressure of briquetting. Chemical tests on briquettes revealed a decrease in the sulfur content and an increase in volatile matter by increasing the amount of biomass. Higher calorific value and lower volatile matter of the beet pulp briquettes in comparison to that of sawdust briquettes make them more favorable as a solid fuel. Adekunle *et al.,* (2015) undertook the proximate and ultimate analyses of Ogboyaga and Okaba coals in Kogi as biocoal briquettes with the aim of presenting the analytical results and ascertaining the optimum biomass composition as a composite domestic fuel. Collected samples were pulverized and blended with sawdust at various mixing proportions, while cassava starch was used as binding agent and calcium hydroxide as a desulphurizer. Study revealed that bio-coal briquettes from Okaba and Ogboyaga coal mines were suitable for the production of environmentally solid fuel that can be used for domestic heat applications. Oji and Monday (2017) produced briquettes of coal and groundnut shell by blending various compositions of coal and grinded groundnut shell using clay/rice starch as a binder and calcium oxide as the desulphurizing agent. Results of the characteristic and post-briquette analysis showed that the different compositions of the briquettes had reasonable calorific value but that of 60% coal:40% groundnut shell briquettes exhibited optimum combustible quality when compared with other compositions. Ikelle *et al.,* (2017) investigated the properties of bio-coal briquette produced from blending cassava stalk and coal. The cassava stalk and coal lumps were carbonized at 160°C, pulverized and used to produce bio-coal briquettes of 10 to 100 %. Briquettes of 40% bio-coal briquette showed improved combustible qualities than others. Ikelle (2017) blended varying compositions from mixtures of coal and agro-waste using bitumen, starch, calcium sulphate and cement as binders with calcium hydroxide as the desulphurizing agent. Coal and rice husk briquettes had higher calorific values than those of coal and corn cob. Tonghuan *et al.,* (2018) studied the effects of lubricant sludge content, forming pressure and drying time on the strength of briquette prepared from pulverized coal. Revealed result based on the single factor tests indicate that the optimum conditions were 12 MPa of forming pressure, 12 hours of drying time and 16% of sludge content. Ikelle *et al.,* (2020) produced and thermally characterized biomass briquettes by blending groundnut husk with coal dust, while starch served as the binder and Ca(OH2) as the de-sulphurizing agent for nine different compositions. The work concluded that appreciable values obtained for thermal properties of the bio-briquettes made them to be adopted for heating purposes rather than open incineration of the wastes. Siswanto (2021) contributed to the solution-finding for the availability of dwindling fossil energy produced charcoal fuel from a biomass mixture of coconut shell waste and coal, using adhesive from meranti wood. Effect of carbonization temperature parameters and the amount of coal used in the mixture on the quality of charcoal fuel was studied. The results revealed that the temperature parameter had a significant effect on the calorific value, water content, and ash content, while the amount of coal mass did not significantly affect the calorific value and ash content but significantly affected the water content of charcoal fuel. Dodyk *et al.,* (2021) attempted to increase the quality of briquettes as solid fuel, added coconut shell to dairy sludge which underwent pyrolysis to produce charcoal and then mixed with coal. The formulation was determined using linear programming, with the decision variables consisting of coal, dairy sludge charcoal, coconut shell charcoal, and binder. The charcoal yield from pyrolysis was 44.35% for dairy sludge and 27.8% for coconut shell charcoal. The optimal briquette formulation was 10% coal, 10% dairy sludge charcoal, 75% coconut shell charcoal, and 5% adhesive with calorific value reaching an acceptable limit. Harry *et al.,* (2021) assessed the properties of bio-coal briquettes made by blending coal with beniseed (sesame seed) stalks. The results indicated that the optimum composition for producing the briquettes lies between 60:40% and 40:60% as these ranges of composition of briquettes gave the lowest ignition time, highest percentage volatile matter and low percentage sulphur content, whereas the 40:60% briquettes had the highest mean calorific value. Yilma *et al.,* (2023) tested the performance of a blended biomass/coal briquette for domestic energy utilization using coal and rice husk under low-pressure densification by means of a manually fabricated hydraulic jack with varying ratios of coal to rice husks. Starch served as the binder, while calcium hydroxide was used as a fixation agent. Proximate analyses of briquettes indicated that biomass/coal briquettes are potential candidates for domestic energy use.



Plate V: Coal and agro bio-coal briquettes (L-R)

**REVIEW FINDINGS**

Notable materials of biomass origin are available for briquettes formation are rice husk, straw, corn cob, saw dust, coal and bio-coal, corn stalk, groundnut shell, wheat straw, palm husk, wood chips, forest wastes, and other agricultural wastes including coconut husks, pineapple peels which have demonstrated some good potential in standalone or in combination. The combination or fusion or two or more materials for briquettes formation have improved thermal properties. Bio-coal briquettes exhibited noble characteristics as a source of solid fuel with decreased amount of dust and soot generation during combustion, shorter ignition time compared to conventional coal briquettes and superior combustion-sustaining properties. Their high breaking strength shown by this briquette is a unique characteristic for easy transportation, while the sandy ash produced could serve for soil improvement in agriculture for crop production. Bio-coal briquette has good combustion characteristics, hence its flame has a significant higher temperature compare to other simple biomass burning or coal. Cementing, adhesives or binders are obtained from starch, papaya, cow dung, natural resin, condemn oil, bitumen, calcium sulphate, pulp sludge and sewage sludge whereas vegetable oil and even sludge have good attributes as congeals for briquettes formation. Calcium hydroxide is a known desulphurizing agent for briquettes formation in minimizing sulphur pollution. For meeting energy performance requirement as a fuel, variables of interest are moisture content, volatile matter, fixed carbon, ash content, calorific value, burning rate, ignition time, specific fuel consumption and flame temperature including other physical properties of less value such as texture, cohesiveness, shape, evenness of surface and appearance of surface.

**CONCLUSION**

Briquettes formation from municipal solid waste, agro waste, faecal sludge, sludge, coal and by-coal briquettes have proved good potential as solid energy fuel in terms of environmental preservation by having low emission levels, relatively cheaper compared to fossil fuel source of energy. The adoption of technology for conversion of these abundant materials found in the environment most especially in the developing countries would help improve access to energy, influence lives of inhabitants economically and safe guard the environment for future generation.

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