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Review

Fuel-Briquetting for Sustainable Development in Developing Countries-A Review

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Abstract

This review covered recent research products on fuel-briquette with emphasis on its production technologies and physical characteristics involving shapes, volumes, resiliencies, and mechanical compressive strengths; combustion properties such as high heating values, volatile matters, moisture contents, ash contents and fixed carbon; chemical analyses for the content of components such as nitrogen, hydrogen, sulfur, oxygen and carbon; emission characterization such as and economic potentials. This review provides opportunities for investors, researchers, governments, individuals, and industries, especially on alternative forms of energy that could be harnessed from waste management and the conservation of forests and its optimal management of carbonaceous wastes and sustainable energy production. Other prominent merits of using fuel-briquettes are the conserving of time in cooking in homes and heating in industries and employment opportunities.

Keywords
Biomass management; fossil waste and reservation; fuel-briquettes; sustainable energy; technology

1. Introduction

In the modern days, fuel-briquette has stimulated a great deal of interest in the world of research due to the prospects of utilizing bio-based wastes, bio-fractions of municipal solid waste (MSW), fossil-based wastes and organic industrial wastes more efficiently with potentials of mitigating levels of environmental pollutions be it land, water or air pollution as supported by the findings of Elehinafe et al. [1]. In developing countries, waste management from various segments including households, large medium and small scale industries have been a key challenge [2, 3]. It is worth mentioning that there are many methodologies in the world's knowledge economy for translating bio-based wastes, fossil-based wastes and bio-fossil-based wastes into fuel-briquettes.

The potential market for fuel briquettes in developing countries is high, motivating investors to invest in converting solid wastes to fuel briquettes. Subject to the feedstocks used and the deployed technologies during preparation, fuel-briquettes are produced in dissimilar shapes and qualities, and thus entail suitable aiming at different market sections of large, medium and small industries and households as reported by Asamoah et al. [4]. Efficiencies in terms of combustion and quality of fuel-briquettes are functions of the properties of solid wastes. These include feedstocks with low moisture, volatile matter contents and ash contents, and high fixed-carbon content [2]. Therefore, the raw feed-stocks used and the fuel-briquette processing steps are to satisfy the characteristics above to achieve the standard quality of fuel-briquettes. According to Asamoah [4] attainment in fuel-briquette and marketing embraces guaranteeing reliable stocks of raw materials with good energy potentials, suitable technologies, facts regarding pollutant characteristics, and constancy in fuel-briquettes' supply and quality.

This review report, highlighted some research products from renowned authors for fuel-briquette production, their methodologies, technologies, results, and market potentials. In this review, the authors reviewed the research products, the inherent parameters such as combustion, physical and chemical properties of raw feedstocks, several procedures involved in fuel-briquette production are identified, as well as the emission properties. This review article will immensely benefit governments, research institutes, investors and academia principally in developing countries.

2. Methodology

The techniques adopted for the research comprised an extensive and intensive review of the literature on fuel-briquette. Resources used encompassed internet materials, current reports and recent publications by note researchers, on bio-based, fossil-based and bio-fossil-based briquetting.

3. Fuel-Briquetting

Fuel-briquetting involves compaction or densification of carbonaceous wastes, sludge or residues into a product of higher density than the raw materials. As shown by Kaliyan and Morey [5] fuel briquettes can be used for heat generation in households, small, and medium-scale industries, or even for power generation in large-scale industries. The handling characteristics of the densified product for packing, transport and storing are also enhanced as pointed out by Stout and Best [6]. The fuel briquettes produced depend on locally available materials such as agricultural residues, domestic carbonaceous wastes, agricultural by-products, charcoal dust, plastic wastes, rubber wastes, tree leaves, water hyacinth, timber residues, sawdust and other wood residues [7]. As pointed out in research conducted by Chou et al. [8] agricultural by-products like rice straw and rice bran are used in fuel-briquette making in China, maize cobs for fuel-briquette in Thailand and coffee husks for the production of fuel-briquettes in Brazil as reported by Felfli et al. [9]. Wilaipon [10] showed that fuel briquettes could function as compliments or replacements to charcoal and firewood for domestic purposes, agro-allied operations, and industrial heating, if produced at low prices and are accessible conveniently. Fuel briquettes are fused using binding agents. Various advantages and disadvantages are associated with fuel-briquette. The main challenge has been that, in many localities, briquettes are too costly compared with existing fuel woods [11]. Fuel briquettes are made of diverse configurations subject to the molds as reported by Ajit et al. [12]. The physical look and combusting properties of fuel briquettes are dependent on the category of feedstocks, molds used and the degree of applied load [13, 14].

3.1 Historical Background of Fuel-Briquetting

The densification of loose carbonaceous feedstocks to make solid fuels was a practice in the past, by civilized societies as put together by Wilaipon [10]. Biomaterials compaction, also known as fuel-briquette of agricultural remains, has been practiced in several countries for years. During the First and Second World Wars, fuel briquettes were discovered to be a vital source of heating and electricity generation [15], using crude technologies. At this time, fuel-briquette of wood wastes (sawdust) and other discarded biomass materials became popular in the continents of Northern and Southern America and Europe due to the deep effect of fuel scarcity [15]. The screw extrusion machine for fuel-briquette, dated back to 1945, was manufactured in Japan. As of April, 1969, there were 638 producing plants in Japan as shown in the work of Grover and Mishra [16]. By the second part of the 19th century, industrial fuel-briquette methods had existed. Simple methods-baling and drying were used. Nowadays, huge and more complicated industrial fuel-briquette machines operating on similar processes are used [17].

3.2 Essence of Fuel-Briquetting

Due to transportation, storage and handling problems, direct combustion of agro-residues is inefficient [18]. On the contrary, fuel-briquette could afford a sustainable approach to better and proficiently exploit agro-based and other biomass residues [15]. More so, fuel-briquettes have advantages as solid fuel over raw bio-materials in terms of: storage and transport and handling conveniences [19]; the ease of furnaces [10]; enhancement in the characteristics of gasification; decrease in the entrainment of particulate pollutants; regularity in sizes and shapes; better substitution for fossil-based fuels [20]; and widespread availability, especially in the less developed nations of the globe leaving the vehicular emissions to be dealt with due to lack of maintenance of the vehicles [21]. Fuel-briquettes lower the costs of fuels for consumers as they are made from bio-wastes like bio-diesel as pointed out by Ayoola et al. [22]. Again, according to [14], fuel-briquetting could create job prospects. Other prominent merits of using fuel-briquettes are conserving time in cooking in homes and heating in industries and declining deforestation [23].

4. Fuel-Briquettes

Fuel briquettes are compacted blocks of carbonaceous waste feedstocks used for household cooking and industrial heating purposes. The finished products of fuel-briquetting stages are referred to as fuel-briquettes. Fuel briquettes are produced from raw carbonaceous materials that are compressed into molds of various geometric configurations [12]. Kaliyan and Morey [5] revealed that fuel briquettes' physical features and combustion characteristics depend on the kinds of bio-materials, the extent of compression and the geometry of used moulds. Generally, fuel-briquettes are with improved physical characteristics and burning rates than the original organic wastes. Making fuel briquettes from charcoal relieves the heavy pressure on the consumption of forest resources.

5. Forms of Fuel-Briquetting

These are the research studies on the production of fuel-briquettes using feedstocks from: virgin biomass, sawdust from wood species, forestry residues, timber wastes, agricultural residues, solid fossils, plastic wastes, sachet water wastes, PET bottles waste, sewage sludge and other municipal solid wastes. The research products are as follows:

Bianca et al [24] worked on producing fuel-briquettes made from banana leaf waste. In their work, semi-dried banana leaves were granulated to particles with sizes ranging between 2 and 5 mm and their moisture content was determined to be 7.8% [25]. In a hydraulic press, the briquettes were compressed with compaction pressure of 18 MPa at two different compression times-0.6 s and 1.0 s. Thermo-gravimetric, differential thermal, proximate and ultimate analyses characterized the fuel briquettes. Following ASTM E872-82 [26], the 50 mm diameter and 50 mm length fuel-briquettes showed moisture content of 7.2% and volatile matter of 75.3%. Following ASTM E1755-01 [26], ash content was 10.7%, fixed carbon content was 14%, sulfur of <0.3%, nitrogen of 0.8%, hydrogen content of 6.23%, carbon content of 44.28%, oxygen content of 37.9% and HHV of 17.7 MJ/kg. The fuel briquettes showed a high loss of mass and maximum energy release between 200°C and 500°C. The mechanical compressive strength for 1-second compression was 5.3 MPa and the fuel-briquette density was 0.99 g/cm^3.

Tamilvanan [27] researched fuel-briquette using waste papers and coconut hulks. The waste papers were used as the binder. In the work the waste papers were shredded into small pieces and soaked for 2 days to activate its binding effect. The coconut hulks were ground into small particles ranging from 1 to 10 mm. Then, the ground particles were mixed with the paper pulp on different mixing ratios such as 80:20, 70:30, 60:40 and 50:50. The pulp-waste-paper mixture was placed in a cylindrical mold and load was applied using a hand plunger. From the analyses, the fuel briquettes had a moisture content of 7.19% by wt. dry basis, volatile matter of 65.44% by wt. dry basis, the ash content of 15.62% by wt. dry basis, the fixed carbon content of 19.08% by wt. dry basis, caloric value of 18.83 MJ/kg. Hence, fuel-briquette can overcome the demand for firewood and other fuels for various burning and heating processes.

Bazargan et al. [28] produced fuel briquettes from the compaction of palm kernel shell (PKS) bio-chars on a laboratory scale. The PKS were first pretreated with temperatures that ranged from 513 to 553 k for durations from 1800 to 5400 s to upgrade the carbon content of the PKS at the expense of the oxygen and hydrogen, increasing the heating value by 5-16%. From the analysis of the fuel-briquettes, the oxygen/carbon ratio, hydrogen and oxygen mass fractions were shown to decrease. The caloric value increased from 18.9 MJ/kg (before treatment) to 22.8 MJ/kg (after treatment at 573 k), and a mass loss of 45-55% was found at different conditions. The compacted fuel briquettes exhibited excellent potential as solid fuel due to their high caloric value, low ash content and high tensile crushing strength.

Oladeji [29] was involved in the making of fuel briquettes from the densification of milled corn cobs. Standard methods of ASTM were adopted to determine the proximate and ultimate analyses of the fuel briquettes produced. The compaction, density, relaxation ratio and percentage expansion were determined. A 5% by weight of cassava starch in the form of gel was used as a binder for a low-pressure technique was adopted. The hydraulic principle was the driving force of the fuel-briquette machine used. After analysis the fuel-briquettes, the results showed that the moisture content was 7.48%. The maximum relative densities, relaxed density and relaxation ratio for the fuel briquettes were 650 kg/m^3, 385 kg/m^3, 1.69 respectively. The heating value of the fuel-briquettes from corn cob was 20,890 kJ/kg while the corresponding compressive strength value was 2.34. It was concluded that the briquette produced would make a good solid biofuel.

In 2013, Oladeji [30] worked on characterizing fuel briquettes produced from rice husk residues which were densified into fuel briquettes. In the first place, the residues were granulated using a hammer mill to 0.6 mm size of particle guided by ASAE 424.1 of the year 2003. A binding agent 5% of cassava starch per weight was used. The ultimate analysis results gave 42.10% (contents of carbon), 5.8% (hydrogen), 51.67% (oxygen), 0.38% (nitrogen), and 0.05% (sulfur). For the proximate analysis, the % content of fixed carbon, ash content, volatile matter and moisture for the fuel briquettes was 13.40%, 18.62%, 67.98%, and 12.67%, respectively. The higher heating value computed for fuel briquettes was 13,389 KJ/kg. The values of 524 kg/m^3, 240 kg/m^3, and 2.22 were obtained for maximum density, relaxed density and relaxation ratio for the fuel-briquettes, respectively. The afterglow time of 354 seconds was recorded, while the propagation rates of 0.10 cm/s were obtained for the fuel briquettes. It found that, during transportation and storage, the fuel briquettes would not break because the value obtained for the relaxed data, was almost equal to the maximum fuel-briquette density.

In the study carried out by Lubwama and Yiga [31], fuel-briquettes were produced using varying pressures from bagasse and groundnut shells after carbonization. Cassava starch and wheat starch were the binding agents. Each 1000 g carbonized groundnut shell and bagasse was mixed with wheat and cassava flour starch in the order of 90, 70, 50 and 30 g. At a compaction pressure of 230 MPa fuel-briquettes were produced from 1000 g of carbonized groundnut shells only, 1000 g of 1000 g groundnut shells with 250 g powdered cassava starch and 1000 g carbonized groundnut shells with powdered wheat starch. From gravimetric, calorimetric, thermal, and mechanical analyses, the energy values for both carbonized bagasse and groundnut shell fuel-briquettes produced using varying pressures ranged from 21-23 MJ/kg for both binding agents. Results from the analyses showed that the values obtained were all above 16 MJ/kg-the average energy value observed for non-carbonized groundnut shell fuel briquettes produced with high applied pressure. A positive effect was also observed in the fuel briquettes developed due to the used binding agents in the carbonized bagasse groundnut shell concerning strength.

Tamilvanan [27] engaged in the preparation of fuel briquettes using sun-dried tree leaves, and waste paper as binding agents. The waste papers were shredded into small pieces and transformed into gum by soaking in water for two days. The sun-dried leaves were ground into particles of sizes that ranged from 1 to 10 mm. Then, the ground particles were mixed with the paper pulp on volume fractions: 80:20, 70:30, 60:40 and 50:50. The mixture was placed in a cylindrical mold, and using a hand plunger, pressure was applied. From the subsequent analyses, the fuel briquettes' moisture content was 6.52% by wt. dry basis, volatile matter of 75.78% by wt. dry basis, the ash content of 12.48% by wt. dry basis, the fixed carbon content of 5.02% by wt. dry basis, and caloric value of 17.3 MJ/kg. It was concluded that the volatile matter was higher than coal, which would make the fuel-briquettes more reactive. In 2013, Tamilvanan [27] prepared fuel briquettes using maize straws and waste papers as binders. The waste papers were shredded and prepared into gumming pulp. The maize straws were ground into particles of variable sizes ranging from 1 to 10 mm. Then, the ground particles were mixed with the gumming pulp on different mixing fractions such as 80:20, 70:30, 60:40 and 50:50. The pulp mixture was put in a cylindrical mold and by means of a hand plunger, the force was applied. Results showed that the fuel briquettes had a moisture content of 8.67% by wt. dry basis, volatile matter of 78.93% by wt. dry basis, the ash content of 14.72% by wt. dry basis, the fixed carbon content of 20.46% by wt. dry basis, caloric value of 18.75 MJ/kg. A cheap low-pressure wet basis technique was compared with a high-pressure dry basis technique. These production methods could offer employment for rural communities and overcome the quest for firewood and other fuels for various processes.

Chinyere et al. [32] produced fuel briquettes from sawdust and corn-starch binder. The fuel briquettes were produced mechanically with a hydraulic-operated machine. The production was achieved by mixing 30 ml, 40 ml, 50 ml of corn starch with 100 g, 150 g and 200 g of sawdust with 75 ml, 100 ml, 125 ml of water in different amalgamations to produce the fuel-briquettes. The sawdust used was sieved to a particle size of 2 mm, a measured quantity of corn-starch binder and water were added and thoroughly mixed with a blending machine at 1000 rpm. The analysis results showed that the briquettes of 30 ml corn starch binder with sawdust of 100 g, 150 g, 200 g were on the averages of 38.2 MJ/kg, 39.5 MJ/kg and 40.4 MJ/kg respectively. As both the sawdust and binder increased, the heating values of the fuel-briquettes increased appreciably. It was also observed that as the mass of sawdust increased from 100-200 g with the same volume of binder the boiling time declined was 100 g:17.09 mins, 150 g:16.02 mins, 200 g:15.92 mins. Also as the volume of the binder increased from 30 to 50 ml with the same mass of sawdust the boiling time diminished that is 100 g, 30 ml:17.09 mins, 100 g, 40 ml:16.16 mins, 100 g, 50 ml:15.32 mins. The preliminary production of fuel briquettes from sawdust and corn starch as a binder was achieved. From the results of the evaluated parameters, it could be deduced that as the volume of binder increased with the same mass of sawdust, the briquettes' performance increased. This showed that corn starch binder is recommended for the processing of other agro-residues into fuel briquettes.

Imoisili et al. [33] characterized fuel-briquettes from sawdust of the specie *Albizia zygia* and sorghum dust of sizes ranging from 100-150 microns, using cassava starch as a binder. Five different compositions of sawdust/sorghum-dust hybrid fuel-briquettes were produced. The samples were kept to dry for two days to a moisture content of 6%, while a hydraulic press was used to produce the fuel-briquettes to the required shape under pressure for 30 min and later dried at 105°C in an oven. The mixing fractions were as follows: 100% sawdust and 0% sorghum dust; 60% sawdust and 40% sorghum dust; 50% sawdust and 50% sorghum dust; 40% sawdust and 60% sorghum dust; and 0% sawdust and 100% sorghum dust. From the results: the fuel-briquettes' moisture content and ash content increased as sorghum dust content increased from 6.83% to 29.70% and from 2.85% to 17.14% respectively. Also as the sorghum dust increased, the heating values increased from 3.83 MJ/kg to 10.43 MJ/kg. The compressive strength increased as the dust increased which varied from 4.94 KN to 15.18 KN. These increases proved that there was interfacial bonding strength between the sorghum dust and sawdust which resulted in increasing compressive strength.

Hamid et al. [34] looked at the torrefaction of biomass materials before densifying into fuel-briquettes to improve their heating values, physical strength and turn of investment (ROI). The influences of variables of the fuel-briquette procedure vis-à-mistype of bio-materials used (rubber seed kernel (RSK) and palm oil shell (POS)), densification temperature, and composition of the binder were examined. Cassava starch was the binding agent used in the work. After RSK and POS were torrefied, the results proved that fuel-briquettes from RSK were better than those from POS in heating values and compaction strengths at the room temperature of the fuel-briquette procedure with the composition of 5% binding agent and 60% water [34]. The maximum load of 141 N was used to compress fuel-briquettes from torrefied RSK while 16 MJ/kg was the heating value from calorimetric analysis. The ROI for the commercial production of POS and RSK fuel-briquettes, from the angle of economic exploration, was projected to be two years with the yearly profit to be 107,428.6 USD after payback.

Mohammed and Olugbade [35] investigated the effect of applied compression pressure, proportions of binding agents and particle sizes of a mixture of palm kernel shells and rice bran on the combustion rate of fuel briquettes produced. The study involved palm kernel shell and rice bran fuel-briquettes of three particle sizes: 2.0, 4.0 and 6.0 mm at compression pressures: 3.0, 5.0, 7.0 and 9.0 MPa. The binding agent used was cassava starch in the ratio of 10, 20, 30, 40 and 50% by weight of mixtures. The burning rates recorded were 2.3, 2.0, 1.9, 1.7 and 1.6 g/min at binding agent proportions of 10, 20, 30, 40 and 50%, correspondingly. It could be resolved that increment in compression pressure, binder ratios and reduced particle size caused a decline in the combustion rate of fuel-briquettes.

Iyiola et al. [36] evaluated the combustion properties of fuel briquettes. *Terminalia superba* sawdust and banana leaves with cow dung as the binding agent in varying mixing ratios. The fuel-briquettes were produced using an automatic press at a constant compression pressure of 1.77 kN/m^2 at mixing fractions 5:1:4, 4:4:2, 3:2:5, and 2:5:3. The fuel-briquettes produced were subjected to combustion tests. Combustion-related properties such as the percentage volatile matter and percentage ash of the fuel briquettes were determined. The compressed density ranged between 517.09 ± 35.40 kg/m^3 and 571.29 ± 28.73 kg/m^3, while the reduction in density which signifies the rate at which the fuel-briquettes declined in density after compression and relaxation ranged between 46.82 ± 2.56 kg/m^3 and 55.81 ± 1.80 kg/m^3 respectively. The results showed that fuel briquettes in ratios of 2:5:3 and 3:2:5 had better combustion properties than others.

Zannikos et al. [37] examined the fuel briquettes from bio-materials in combination with plastic materials (polyethylene terephthalate (PET)) for household use. The characteristics associated with the combustion of the fuel briquettes in an open fireplace were examined. It was established that the configuration of the fuel briquettes did not affect the emissions associated with the smoke generated. It was observed that the fuel-briquettes at a small fraction of PET, the manners in the combustion were more stable due to an increase in oxygen supply. The levels of smoke fell between the 3rd grade and 4th grade of the number scale for smoke. At the determination of the CO emission, it was revealed that the combustion of the PET in the mixture with bio-materials increased the emissions of carbon monoxide from 10% to 30% in comparison to CO emission from bio-materials (sawdust) that was used as the control standard.

Olorunnisola [38] investigated the properties of fuel briquettes produced from hammer-milled coconut husk particles and shredded waste papers. Using a piston pressing machine, the mixture was densified into fuel-briquettes at a pressure of 1.2×10^3 N/m^2. The ratios, by weight, of mixing were 25:75, 15:85, 5:95 and 0:100. Results showed that fuel-briquettes produced from waste paper (100%) and a mixture of waste paper and coconut husk in the ratio 5:95 displayed, on drying, the leading rectilinear expansion, although minimal. As the moisture contents of the fuel briquettes produced ranged from 5.4% to 13.3%, there was no observable variation with the rise in the coconut husk portion of the fuel briquettes. An inverse correlation was shown between relaxation ratio and fuel-briquettes' compacted/stress-free density. The average resilience rating of the fuel briquettes surpassed 95%. It was established that firm fuel briquettes could be developed from waste papers combined in ratios with granulated coconut husk.

Katimbo et al. [39] explored the production of biofuel-briquettes from seed covers of mango fruits to serve as a solid fuel for households and factories. Due to their abundance in the country and high fiber content (good property for fuel-briquette), mango-seed covers were chosen. Seed covers were sun-dried and crushed to particles two millimeters in size and compacted using different binding agents-cassava starch, cassava starch-red soil and cassava starch-clay soil. The mixing ratios of: 16:1:4 (seed-cover: red soil: starch:), 1:4 (starch: seed-cover) and 9:1:2 (seed cover: clay soil: starch), were discovered to be the best for the fuel-briquettes produced. Katimbo et al. [39] subjected the fuel briquettes to analyses to validate their appropriateness as solid fuels. After analyses, fuel-briquettes bonded with only starch had higher fuel properties with low moisture content-11.9%, ash content-2.8%, volatile matter-16.0%, fixed carbon content–69.3%, breaking strength-34 N, compressive strength–273 n/mm^2 and calorific value–16, 140 kJ/kg compared to starch-red soil and starch-clay soil fuel-briquettes. The attendant gas emissions were: CH_x-0.0021%, CO-0.178%, CO_2-1.14% and no NO_x.

Tamilvanan [27] reviewed the literature on developing fuel briquettes that could substitute conventional fuels–coal, wood, Liquefied Petroleum Gas, and charcoal. Fuel-briquette technology, a kind of eco-friendly coal technology, would enable us to check global warming and serve to preserve our forest resources (add references). The feedstocks for fuel-briquetting such as straws of harvested crops, bagasse from sugarcane, stalks of maize, leaves and husks of a coconut, shells of groundnut, husks of rice, and sawdust with municipal waste papers as a binding agent were pointed out. Fuel briquettes could be used in place of fossil fuels for domestic cooking and industrial heating processes. Tamilvanan [27] opined that experimental work should focus on developing methods to produce fuel briquettes of consistent quality. The researcher further emphasized that the effects of process parameters-calorific values, shapes, moisture contents, and densities on fuel briquettes with various combinations should be studied. The review concluded that fuel-briquette could actually offer a means of managing waste while providing business opportunities in fuel production in local communities.

Imeh et al. [40] explored the production and analysis of biomass fuel-briquettes using solid wastes from tannery. The wastes comprised flesh, hair, buffing dust, and chrome shaving collected from a tannery factory in Kano, Nigeria. Six different fuel briquettes were produced. Proximate and scanning electron microscopy (SEM) analyses were carried out on the fuel briquettes. Thermal efficiency, durability and compaction strength were determined for the fuel-briquette developed. The fuel-briquettes had energy values ranging from 18.632 MJ/kg to 24.101 MJ/kg as good as other fuel sources such as coal that ranged between 20.000 MJ/kg and 24.730 MJ/kg. The resilience of the fuel briquettes ranged between 98.12% and 99.77%. This study concluded that solid wastes from tanneries could be converted into fuel briquettes, thereby serving as a source of viable energy generation that is environmentally friendly, and cost-effective compared to fossil fuels.

Sánchez et al. [41] focused on producing fuel-briquettes from sawdust (waste wood) generated by timber firms sited in the Piura Region, Peru. Through processes of densification and dehydration, fuel-briquettes from sawdust were produced with the following analytical findings: the heating value of 19.8 MJ/kg, density of 894 kg/m^3, ash content of 1.3%, fixed carbon content (15.29%,) and volatile matter content (83.41%). The obtained results showed that fuel-briquettes from sawdust are a good alternative for the illegal fuels coming from forest reserve through logging in Piura that are currently used as charcoal and firewood in homes by families amounting to 55.81% of the populaces in the region. To study the recognition of alternative fuel briquettes, seminars, up to eleven, were organized to reach up to 600 nuclear families and test produced fuel briquettes in 127 homes in five poor-income zones of the Piura region.

Onuegbu et al. [42] conducted studies on ignition time and water boiling test of coal compated with biomass fuel-briquettes composites. The biomass was collected, sun-dried, chopped and milled to pass through 4 mm standard sieve. The sub-bituminous coal sample was sun-dried, broken into small pieces and milled to pass through 1 mm sieve. The results showed that the fuel-briquettes from coal had a higher heating value of 20.6 4 kJ/g, fixed carbon content of 30.65% and ash content of 18.27% than the fuel-briquettes from biomass but lesser volatile matter of 43.33% by mass. Coal has more mineral matter than the biomass materials, as indicated the ash contents indicate. The coal concentration in blends of coal and biomass would greatly impact of the size of ash that coal-biomass fuel-briquettes would produce. These coal-biomass fuel-briquettes are very effective as the worth of any fuel-briquette hangs on the ensuing factors: its capability to make available adequate time of heat, kindle easily without any risk, make less smoke, produce less ash as these could create menace during domestic cooking and be durable sufficiently for safe storage and conveyance.

Benk [43] embarked on the utilization of the binding agents prepared from coal tar, pitch and phenolic resins for the production of metallurgical quality fuel briquettes from coke breeze and investigated their high-temperature carbonization behavior to reduce the incurred cost of the coke fuel-briquettes formed which could be used as an alternative to the fuel-coke for blast furnace in metallurgy. The binding agents investigated were the nitrogen-blown coal tar pitch, the blend of air-blown coal tar pitch and air-blown coal tar pitch with the phenolic resin blends. From the attendant analysis, nitrogen-blown coal pitch gave the weakest fuel briquettes. Coke breeze was carbonized at a temperature above 670 and cured at 200°C for 2 h when only the air-blown coal tar pitch was used as a binding agent. Using air-blown coal tar pitch only as a binding agent would not be cost-effective for it would involve greater temperature at the carbonization phase. From a blend of air-blown coal tar pitch, phenolic resins and coal breeze, fuel-briquettes were also produced and cured at 200°C for 2 with a stronger tensile strength-50.45 MN/m^2. Carbonization at different temperatures from 470 to 950°C, the strength of the two categories of the cured fuel-briquettes was constantly rising and reached 71.85 MN/m^2. Properly cured fuel briquettes from the above raw materials can be used as substitutes for coke use in metallurgical kilns.

Shimasaki et al. [44] engaged in the production of fuel-briquettes from coal at a cheap energy cost to save steps of heating or steps of drying. The process comprised: the addition and mixing of mass parts of dry starch, from 1 to 10, to coal that has at least 15% by mass of moisture content and contains at least 50% by mass of granules of at least 5 mm in size to form 100% by mass of a mixture; with the surfaces of the fuel-briquette products coated with 0.1 to 5 portions by mass of a heavy oil component concurrently with or after pressure. The blend was compacted by a fuel-briquette machine with the concaves of the fuel-briquettes formed on the roll surface. The coal-briquettes would be economical, highly strong, and highly water-resistant.

6. Conclusion

The research comprised an extensive and intensive literature review on fuel-briquette. by note researchers, on bio-based, fossil-based and bio-fossil-based briquetting. The findings from the review of the experts include: molding of fuel-briquettes in various geometries and qualities based on used technologies and raw organic materials in production. So, the producers of fuel briquettes can decide on the applied technologies; extent of drying, adequate pressure, binding agent and resilience to meet the choice of the end users – households and industry. These are also factors considered for the transportation and storage of fuel briquettes. Thorough compaction leads to reduced emissions emanating from the burning of fuel briquettes. The search shows that sustainable enterprises in fuel-briquette are achievable based on the abundant availability of raw materials in developing countries, available processing technologies and market prospects.

7. Recommendation

This review paper advocates for stakeholders like governments, investors, research institutes and academia to find a sustainable solution to the energy problem and menace from carbonaceous solid wastes via fuel-briquette. It is recommended that applied technologies; extent of drying, adequate pressure, binding agents and resilience to end users, and pass through international standards thereby enhancing the guidelines for handling, utilization and pollution control.

Author Contributions

Dr. F. B. Elehinafe conceptualized the idea and wrote the manuscript while Dr. O. B. Okedere reviewed and edited the manuscript.

Competing Interests

The authors have declared that no competing interests exist.

References

1. Elehinafe FB, Okedere OB, Fakinle BS, Sonibare JA. Assessment of sawdust of different wood species in Southwestern Nigeria as source of energy. Energy Source Part A. 2017; 39: 1901-1905.
2. Adetunji A, Isadare D, Akinluwade K, Adewoye O. Waste-to-wealth applications of cassava–A review study of industrial and agricultural applications. Adv Res. 2015; 4: 212-229. doi: 10.9734/AIR/2015/15417.
3. Atta A, Aminu M, Yusuf N, Gano Z, Ahmed O, Fasanya O. Potentials of waste to energy in Nigeria. J Appl Sci Res. 2016; 12: 1-6.
4. Asamoah B, Nikiema J, Gebrezgabher S, Odonkor E, Njenga M. A review on production, marketing and use of fuel briquettes. International Water Managerment Institute; 2006. Available from: https://www.iwmi.cgiar.org/Publications/wle/rrr/resource_recovery_and_reuse-series_7.pdf.
5. Kaliyan N, Morey RV. Factors affecting strength and durability of densified biomass products. Biomass Bioenergy. 2009; 33: 337-359.
6. Stout B, Best G. Effective energy use and climate change: needs of rural areas in developing countries. Agric Eng Int. 2001; III. Available from: https://cigrjournal.org/index.php/Ejounral/article/view/215/209.
7. Rousset P, Caldeira-Pires A, Sablowski A, Rodrigues T. LCA of eucalyptus wood charcoal briquettes. J Clean Prod. 2011; 19: 1647-1653.
8. Chou CS, Lin SH, Lu WC. Preparation and characterization of solid biomass fuel made from rice straw and rice bran. Fuel Process Technol. 2009; 90: 980-987.
9. Felfli FF, Rocha JD, Filippetto D, Luengo CA, Pippo WA. Biomass briquetting and its perspectives in Brazil. Biomass Bioenergy. 2011; 35: 236-242.
10. Wilaipon P. Physical characteristics of maize cob briquette under moderate die pressure. Am J Appl Sci. 2007; 4: 995-998.
11. Kaliyan N, Morey RV. Densification characteristics of corn cobs. Fuel Process Technol. 2010; 91: 559-565.
12. Kaur A, Roy M, Kundu K. Densification of biomass by briquetting: A review. Int J Recent Sci Res. 2017; 8: 20561-20568.
13. El-Saeidy EA. Technological fundamentals of briquetting cotton stalks as a bio-fuel. Germany: Faculty Agriculture and Horticulture, Humboldt University; 2004.
14. Lela B, Barišić M, Nižetić S. Cardboard/sawdust briquettes as biomass fuel: Physical–mechanical and thermal characteristics. Waste Manage. 2016; 47: 236-245.
15. Zhang J, Guo Y. Physical properties of solid fuel briquettes made from Caragana korshinskii Kom. Powder Technol. 2014; 256: 293-239.
16. Grover, P.D. and Mishra, S.K. Biomass briquetting: Technology and practice. Regional Wood Energy Development Programme in Asia, Food and Agricultural Organization: 1996; Field Document No. 46.
17. Lardinios I, van del Klundert A. Organic waste: Options for small-scale resource recovery (Urban solid waste series 1). Gouda, Netherlands: Waste; 1993.
18. Li Y, Liu H. High-pressure densification of wood residues to form an upgraded fuel. Biomass Bioenergy. 2000; 19: 177-186.

19. Ifa L, Yani S, Nurjannah N, Darnengsih D, Rusnaenah A, Mel M, et al. Techno-economic analysis of bio-briquette from cashew nut shell waste. Heliyon. 2020; 6: e05009.
20. Ndiema C, Manga P, Ruttoh C. Densification characteristics of rice straw briquettes. J Energy Inst. 2002; 75: 11-13.
21. Odunlami OA, Elehinafe FB, Oladimeji TE, Fajobi MA, Okedere OB, Fakinle BS. Implications of lack of maintenance of vehicles on ambient air quality. Int J Mech Eng Technol. 2018; 9: 647-654.
22. Ayoola A, Oresegun O, Oladimeji T, Eneghalu C. Energy analysis of biodiesel production from waste groundnut oil. Int J Res Eng Appl Sci. 2019; 6: 202-208.
23. Navalta CJ, Banaag KG, Von Adrian OR, Go AW, Cabatingan LK, Ju YH. Solid fuel from Co-briquetting of sugarcane bagasse and rice bran. Renew Energy. 2020; 147: 1941-1958.
24. de Oliveira Maiaa BG, Souzab O, Marangonib C, Hotzaa D, de Oliveiraa APN, Sellinb N. Production and characterization of fuel briquettes from banana leaves waste. Chem Eng Trans. 2014; 37: 439-444.
25. ASTM standards. Standard test method moisture analysis of particulate wood fuels. Pennsylvania: ASTM International, West Conshohocken; 2006; ASTM E871-82(2006).
26. ASTM standards. Standard test method for volatile matter in the analysis of particulate wood fuels. ASTM International; 2013; E872-82. Available from: https://tajhizkala.ir/doc/ASTM/E872-82%20(Reapproved%202013).pdf.
27. Tamilvanan A. Preparation of biomass briquettes using various agro-residues and waste papers. J Biofuels. 2013; 4: 47-55.
28. Bazargan A, Rough SL, McKay G. Compaction of palm kernel shell biochars for application as solid fuel. Biomass Bioenergy. 2014; 70: 489-497.
29. Oladeji J. Fuel characterization of briquettes produced from corncob and rice husk resides. Pac J Sci Technol. 2010; 11: 101-106.
30. Oladeji J. Comparative study of briquetting of few selected agro-residues commonly found in Nigeria. Pac J Sci Technol. 2012; 13: 80-86.
31. Lubwama M, Yiga VA. Development of groundnut shells and bagasse briquettes as sustainable fuel sources for domestic cooking applications in Uganda. Renew Energ. 2017; 111: 532-542.
32. Chinyere D, Asoegwu S, Nwandikom G. An evaluation of briquettes from sawdust and corn starch binder. Int J Sci Technol. 2014; 2: 149.
33. Imoisili PE, Ukoba KO, Daniel BA, Ibegbulam M. Production and characterization of hybrid briquette from biomass. Br J Appl Sci Technol. 2014; 4: 1534.
34. Hamid MF, Idroas MY, Ishak MZ, Zainal Alauddin ZA, Miskam MA, Abdullah MK. An experimental study of briquetting process of torrefied rubber seed kernel and palm oil shell. BioMed Res Int. 2016; 2016: 1679734.
35. Mohammed T, Olugbade T. Burning rate of briquettes produced from rice bran and palm kernel shells. In J Material Sci Innov. 2015; 3: 68-73.
36. Iyiola E, Ogunleye M, Olufemi B, Owoyemi J, Ayanleye S. A study of combustion properties of briquettes produced from a blend of sawdust-banana leaves and cow dung in nigeria. Pro Ligno. 2019; 15: 30-37.
37. Zannikos F, Kalligeros S, Anastopoulos G, Lois E. Converting biomass and waste plastic to solid fuel briquettes. J Renew Energy. 2013; 2013: 360368.

38. Olorunnisola A. Production of fuel briquettes from waste paper and coconut husk admixtures. Cigr E J. 2007; 9: EE 06 006.
39. Katimbo A, Kiggundu N, Kizito S, Kivumbi HB, Tumutegyereize P. Potential of densification of mango waste and effect of binders on produced briquettes. Agric Eng Int. 2014; 16: 146-155.
40. Onukak IE, Mohammed-Dabo IA, Ameh AO, Okoduwa SI, Fasanya OO. Production and characterization of biomass briquettes from tannery solid waste. Recycling. 2017; 2: 17.
41. Sánchez EA, Pasache MB, García ME. Development of briquettes from waste wood (sawdust) for use in low-income households in Piura, Peru. London, UK: Proceedings of the World Congress on Engineering; 2014.
42. Onuegbu T, Ekpunobi U, Ogbu I, Ekeoma M, Obumselu F. Comparative studies of ignition time and water boiling test of coal and biomass briquettes blend. IJRRAS. 2011; 7: 153-159.
43. Benk A. Utilisation of the binders prepared from coal tar pitch and phenolic resins for the production metallurgical quality briquettes from coke breeze and the study of their high temperature carbonization behaviour. Fuel Process Technol. 2010; 91: 1152-1161.
44. Shimasaki K, Takasago-Shi, Deguchi T, Takasago-Shi, Sugita S, Takasago-Shi, et al. Coal briquette and production. United States Patent Application Publication; 2003. Available from: https://patentimages.storage.googleapis.com/57/79/0b/eed2f8cd6ca926/US20030046864A1.pdf.