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Solid fuel briquette from biomass: Recent trends

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Abstract. Solid fuel briquette from biomass materials has gained considerable attention as sustainable replacement source of energy. The characteristics of briquette are imperative to ensure its effectiveness as fuel in a long run. This paper is aimed to summarize the key properties of solid briquette made from various natural and waste-based resources, and to highlight the future research directions in the briquette manufacture. The commentary is expected to shed insight towards the greener, cleaner, and efficient briquette materials.

Keywords**:** briquette; biomass; calorific value; heating retention; solid fuel.

1. Introduction

The advancement in thermal and electricity generation is the catalyst of economic growth and nation development [1]. Harnessing the conventional energy resources, however, has resulted in the release of more greenhouse gases, largely due to the combustion of natural gas, oil, and coal [2]. Data recorded in Portugal over the period of six decades showed a 7-fold increase of CO_2 emissions from 4 million tons/year to 28 million tons/year for thermal and electrical energy production only [3]. Briquette is a compressed biomass material and a promising solid fuel to initiate and preserve fire. It has shown a great market demand to balance out the fluctuation of oil prices, global warming, and detrimental effects of CO_2 emission into the atmosphere. Briquette has emerged as a greener solution to economic and strategic initiatives to curb the global warming. Several known materials to produce briquette are rubber, plastic, forestry, and agricultural wastes [4]. The pre-mixed formulation of shredded material and suitable binder is typically compressed to form briquette. Binders are additive incorporated into the mixture to enhance the durability of briquette. Commonly, they are of natural origin, safe and environmentally friendly.

Briquette has been utilized in various fields encompassing industrial and household applications. In the past, there has been an inadequate interest to explore briquette as solution to energy issues because of the plentiful of fossil fuels. Now, as the world is facing the shortage of non-renewable fossil fuels with the inexorable rise of the price, the shift in recent scenario has triggered attempts and efforts in outsourcing briquette as cheaper and sustainable energy replacement.

The immediate markets for briquette consist in small and medium industries and households, mainly for water heating and cooking activities. In contrast to the conventional solid fuels like charcoal and firewood, briquette can be tailored to cater specific requirements and applications. It came with different compositions, shapes and dimensions, smoke emission levels, types of stoves and burning times. Briquette could entirely replace coal as it generally exhibits longer burning capacity and is efficient in preserving the fire. In addition, the production would be more cost attractive to be mass-produced, especially when the materials are classified as industrial residues such as discarded tires and sludges.

The emergence of solid fuel briquette is seen as an energy disruptor to a world that is highly dependent on conventional fuels. Nowadays, it has already been applied in manufacturing of tiles and bricks, harvesting of agricultural products, bleaching of textile products, fueling bakeries and distilleries, and powering boilers for steam generation. The key success of briquette as solid fuel lies upon its characteristics. Therefore, this commentary is aimed to compile and highlight the pertinent properties of briquette from various feedstocks and to shed insight towards its challenges as fuel alternative. The perspectives are discussed to pave ways for future research.

2. Briquette production

Briquette is generally produced from natural biomass materials, including grass and tree leaf [5], rice straw [6], empty fruit bunch [7], bamboo sawdust [8] and sugar-cane bagasse or its byproduct fly ash, after recovering a charcoal fraction from it [9]. Rubber and plastic waste [10] may also be used to manufacture briquette because of their rich energy content [10]. The feedstock materials are often undergone heat treatment at 300 °C to 500 °C under anoxic environment to liberate light volatiles so as to increase the carbon content and calorific value. In the briquette manufacture, the material is shredded into small pieces, then compressed into various sizes and shapes of compact logs/pellets.

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The use of binders like cassava starch, molasses and maltodextrin in the briquette formulation has been widely explored and reported [6-9] to ensure better grip of particles, hence increasing the durability of solid during heating. The binder is mixed with the biomass particles in the presence of water or solvent at an appropriate ratio to form dough-like texture. After it is being molded and compressed into desired dimensions, the solid is finally allowed to dry and harden. A slow drying rate is preferred to prevent cracking, as the visible crack structure signifies the poor compressive strength of a briquette. The amount of binder is normally kept at a low amount to avoid unnecessary compromise in calorific value as its carbon content is much smaller than the base material. Conversely, successful attempts to produce binder-free briquette have also been reported [2, 5]. Table 1 summarizes the characteristics of briquettes produced using various feedstocks.

Table 1. Feedstock materials and characteristics of briquette.

Material	Shape	Compressive strength	Density (kg/m^3)	Dimension (cm)	Binder used	Calorific value (MJ/kg)	Ref.
Rice husk and bran	Cylindrical	2.54 kN	441	2.5-10 D	Cassava starch Okra stem gum	16.1	[24]
Rice husk and corn cobs	Cylindrical	176 kN	570	3.2 D	Cassava	-	[25]
Rice milling by-products	Cylindrical with whole	-	600	-	Palm press fiber Palm press sludge	16.9 - 19.2	[26]
Rice straw	Cubic	-	-	4 L 4 W 3.5 H	Rice bran Sawdust of *Acacia confuse* Soybean residue	-	[6]
Empty fruit bunch	Cylindrical	-	-	4.1 D 4.7 L	Cassava starch	17.2	[7]
Paper and wheat straw	Cylindrical	38.2 MPa	0.81	2.5 D 6 L, 1.3 D 4 L	-	17.3	[15]
Bamboo sawdust	Cylindrical	-	416	1.2 ID 3.8 ED 4 L	Molasses	21.3	[8]
Eucalyptus wood	Cylindrical	14 MPa	1.06	3.25 D 1.71 L	-	18.6 - 21.3	[23]
Sugarcane bagasse fly ash	Cylindrical	>7 MPa	1.12	3 D	Cassava starch	25.6	[9]
Pulp and textile sludge	Cylindrical	-	1.19 - 1.34	1 D 1-5 L	-	8.85 - 10.6	[27]
Lignite	Cylindrical	1.23 - 2.94 MPa	-	1.8 D 2 L	Clay Waste pulp liquor	-	[28]
Anthracite	Ball shape	-	-	4-6 D	Asphalt and modified coal	-	[29]
Coke briquette	-	-	-	2.2 ID	Phenolic resin Coal tar pitch	27.6 - 28.5	[30]
Textile industry residues and bio-sludge	Circular	1.51 kPa	1.18 - 1.27	-	-	21.8	[31]
Carbonized and leached material	Cylindrical	-	-	1 D 1.3 L	Grape must	-	[32]
Spent bleaching earth	Cylindrical	1.30 MPa	-	2 ID 8 ED 5 L	Maltodextrin	7.28	[33]
Municipal waste composting char and sawdust	Cylindrical	2 MPa	1.24	1.3 ID 3.8 ED 15 L	Slop waste	3.47	[34]
Fine-grained waste	-	-	-	-	Molasses Potato starch	21.5 - 23.7	[35]
Mix of corncob and oil palm trunk bark	Cylindrical	≤ 7 Mpa	-	-	Wastepaper pulp	17.8	[36]
Cassava waste	Cylindrical	204 Mpa	119	3.5 ID 16 L	-	17.1	[37]
Mix of corncob, sugarcane bagasse and rice husk	Cylindrical	-	625	5 D 5 L	Wheat flour	27.1	[38]
Cashew nutshell	Hollow cylindrical	29.4 MPa	-	-	Tapioca flour Ethanol	29.5	[39]

Material	Shape	Compressive strength	Density (kg/m^3)	Dimension (cm)	Binder used	Calorific value (MJ/kg)	Ref.
Palm kernel shell	Cubic	-	1220	2.5 D 10 L 6 H	Cassava starch	18.7	[40]
African oil palm empty fruit bunch	Cylindrical	44.5 kN	934	-	-	18.6	[41]
Mix of sawdust, rice, and coconut husks	Cylindrical	89.1 kN	-	3 D 6 L	Cassava starch	24.7	[42]

D = diameter; L = length; H = height; ID = internal diameter; ED = external diameter; W = width.

3. Characteristics of briquette

3.1. Moisture content

Moisture content is defined as the amount of bound water that naturally remains inside the material matrix. It affects the strength and density of the compacted materials [11]. A high moisture content is not desirable for a briquette, although the material has undergone compression at high pressure. The briquette is prone to disintegrate and collapse as the moisture occupied the interstices between the solid particles.

The moisture content of a briquette is suggested to be in the range of 8 % - 10 % [12]. Briquette with minimum moisture content can be produced by controlling the amount of water in its formulation. The use of excess water might entrap inside the compressed matrix, wherein it may be difficult for it to find its way to the surrounding during the drying process. If it does able to escape, the formation of pathways and tunnels may as well result in the fragility of the pellets. This is also tied-up with the drying mechanisms, in which the slow drying at surrounding air as opposed to the rapid oven-drying could prevent the fracture and failure in structural integrity. In addition, the use of volatile solvents such as ethanol as possible replacement to water in the briquette formulation is also recommended as they are easily vaporized at ambient temperature, thus minimizing the moisture content.

3.2. Compressive strength

Compressive strength is the extent of stress compression that is capable to be endured by the pellets when they are stacked and crushed by a screw conveyor [13]. It reflects the rigidness and durability of the briquette. The biomass-based briquette with a dimension of 48.5 mm (diameter) × 50.0 mm (length) was able to endure a maximum compressive stress of 49 MPa [14]. Often, a high compressive strength is linked with a small moisture content and a high compaction pressure [15].

Briquette in pellets form with high compressive strength implies the structural integrity to sustain longer heating and efficient transfer of heat. When the briquette is collapsed and disintegrated into its powder form, there will be significant loss in the heating potential because of the increase of particles' surface area which are more likely to glow rather than burn.

3.3. Durability/abrasive resistance

The quality of solid fuel lies upon its density and durability. The test of durability describes the production of fine powders when the briquette is subjected to mechanical handling. The durability is categorized into three tiers based on ASABE Standard S269.4 (2003) [16], i.e., high (> 80 %); medium (70 % - 80 %) and low (< 70 %). It can be affected by several factors, such as die pressure, temperature, properties of feedstock, types of binders, size and dimension, and moisture content.

The durability of peanut hull pellets shows an increasing pattern to a maximum percentage of 90.3 % with the presence of 9.1 % moisture [16]. A further increase in moisture, however, has resulted in a decline of durability to 76 %. The pellets of alfalfa and switchgrass also demonstrate similar durability characteristics when subjected to varying moisture contents [16]. In a related work, a 0 % durability was recorded for corncob briquette produced at 25 °C, while the magnitude considerably improved to 90 % with a unit density in excess of 1100 kg/m^3 when the moisture is about 10 % at 85 °C [13].

The durability of briquette can also be influenced by the post-production conditions, including handling and storage. In light of this, a thorough understanding of the entire factors affecting the durability in the manufacture of briquette is urgently required to move the industry forward [17].

3.4. Density

Density is defined as the mass over the volume of a material. A solid fuel briquette should possess high density, i.e., more mass per unit volume, that can be translated into its durability, energy content and combustion speed. This characteristic is also important to ease the transportation and lowering transportation specific costs. Husain *et al.* [18] reported the relationship between the product density and the briquetting pressure. Mani *et al.* [19] highlighted how the pressure, moisture content, and particle size affect the density of pellets made from wheat straw, barley straw, corn stover, and switchgrass. They reported the highest pellet density by corn stover with a particle size of 3.2 mm and moisture content of 2 %. Demirbas [15] concluded that the density is a function of briquetting time, wherein a higher density of pellet is obtained from a longer briquetting time. From the economic perspective, however, the briquetting time should be kept minimum to warrant productivity. Notwithstanding that, it is always essential to ensure the coherence of the briquette against crack and particle separation while concentrating on the density [20]. The use of binder, sufficient amount of pressure and thorough drying are among the useful strategies to preserve the characteristics of solid fuel briquette.

3.5. Calorific value

The amount of energy released during a complete combustion of a unit mass of briquette is determined by the calorific value. It can be measured by a standard method using bomb calorimeter. A high calorific value indicates that the combustion produces a high thermal energy. From Table 1, the briquettes exhibit a somewhat high energy content ranging from 8 to 30 MJ/kg, comparable to conventional solid fuels such as anthracite coal (32.5 MJ/kg) and dried firewood (21.7 MJ/kg). Generally, the magnitude depends on the carbon content of the base material for briquetting. In some studies [4, 9], the material is initially subjected to pre-treatment (carbonization) to enhance the carbon content, thus increasing the calorific value. The use of binder in briquetting may decrease the calorific value if the amount is too excessive. Muraina *et al*. [21], and Sing and Aris [22] reported a slight drop in the calorific value when the binder is incorporated with briquette. The selection of binder with the right amount is the key to maintain the high calorific value. Apart from that, briquettes containing high moisture and ash may as well result in low energy content, which renders more attention on the selection of base materials to produce briquette.

3.6. Water absorption

Water absorption is different from moisture content of a briquette, even though they can be interrelated. This phenomenon is common especially for base material and binder that are hygroscopic (water-absorbing) in nature and contain hydrophilic surface functionalities to attract moisture from the surrounding. The effect is more prominent when the briquette is porous or less compacted, in which the water molecules can lodge on the loose texture. A simple test to determine water absorption capacity can be done by soaking the pellet in water for 2 h and measure the amount of water retained on the material. Araujo *et al*. [23] concluded that the briquette with high water absorption bears poor energy content and is not economical for transportation. Compression alone may not be effective to overcome the inherent water absorption properties. The prior selection for briquette formulation and pre-carbonization of base material could be exercised to minimize the impacts of water absorption in briquette.

4. Concluding remark

Agricultural biomass such as bagasse, corncob and oil palm residues are examples of natural materials for briquette production. Residues and sludge from industries have also been exploited as alternative sources of briquette. The success of briquette formulation relies upon its characteristics, including shape and dimension, compressive strength, density, type of binder, and calorific value. Often, the higher the carbon content of the base material, the higher would be the calorific value of the briquette. Nonetheless, the sustainability of the briquette material as effective fuel source is contested by its heating retention amid the high calorific content. As heating retention is imperative to ensure the prolongation of the heat transfer process, it is therefore cannot be simply neglected from the list of characteristics. Surprisingly, this is not widely discussed and elaborated in much of published literature, and no proof has been provided in previous works to validate the heating retention of briquette produced. Thus, standard set-up and procedures to conduct heating retention test should be developed for future research in briquette manufacture. This may include the compartment dimension, air flowrate, fuel source or temperature, and mass and dimension of briquette.

The quest for briquette manufacture is escalating due to demand for cheap and sustainable source of solid fuel. New class of feedstock originated from industrial by-products and sludges has been ventured as alternative briquette. The strategy undeniably supports the Sustainable Consumption and Production of SDG 12. However, care should be exercised as the material could release unexpected toxic gases upon combustion such as dioxin, furan, NOx, and SOx, hence polluting the surrounding air and jeopardizing the health of nearby inhabitants. To use industrial residues and sludges for briquette is risky without comprehensive review and assessment on the material composition including general elements, minerals, and volatile compounds. Research is therefore needed to analyze the gases released during combustion to ensure their compliance with environmental standards for domestic and industrial applications.

Conflicts of interest

The authors declare no conflict of interest regarding the publication of this paper.

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