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A LITERATURE REVIEW OF THE BRIQUETTING MACHINE

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Abstract:

The global use of fossil fuels has engendered widespread issues, such as climate change and adverse effects on public health. Many developing nations annually generate substantial quantities of biomass wastes, often mishandled or disposed of in environmentally detrimental ways. Nonetheless, there exists potential to transform these wastes into high-density, energy-efficient briquettes through a process known as densification. This offers a compelling alternative to traditional fossil fuels, presenting an opportunity to alleviate the adverse impacts of climate change. The present paper conducts a comprehensive review of biomass briquetting, encompassing the utilized resources, process parameters, associated technologies, and the resultant briquette quality. By synthesizing extant knowledge, the literature review aspires to furnish a thorough comprehension of the current state, challenges, and future prospects of briquetting machinery. This compilation of insights serves as a valuable resource for researchers, practitioners, and policymakers involved in the domain.

Keywords: Briquettes, Agro-residues, densification, process parameters

1. Introduction

Regrettably, numerous developing nations generate substantial quantities of agro residues, yet their utilization remains inefficient, leading to extensive environmental pollution. Prominent among these residues are rice husk, coffee husk, coir pith, jute sticks, bagasse, groundnut shells, mustard stalks, cotton stalks, and sawdust (Ibitoye et al., 2021). The primary impediment associated with the conventional combustion of these residues on grates lies in the markedly low thermal efficiency, resulting in pervasive air pollution (Senchi & Kofa, 2020). Indeed, the conversion efficiencies may plummet to as low as 40%, accompanied by particulate emissions in the flue gases surpassing 3000 mg/Nm^3. Moreover, the disposal of a significant proportion of unburnt carbonaceous ash poses a considerable challenge (Tekle Asresu, 2017).

The consideration of the impact associated with the incineration of rice husk is crucial, given that it can constitute more than 40% of the total feed burnt. In Ludhiana (Punjab), for instance, the burning of 2000 tonnes of husk results in the daily generation of approximately 800 tonnes of rice husk ash (Thekedar et al., 2021). The adoption of briquetting technology for husk presents a dual advantage, not only mitigating pollution concerns but also harnessing this valuable industrial/domestic energy resource(Emmanuel et al., 2023). While biomass briquettes are acknowledged as a viable alternative fuel for wood, coal, and lignite, challenges, particularly machine failures, have impeded their widespread adoption in many developing nations (Dinesha et al., 2019). Nevertheless, successful practices of biomass densification, encompassing the briquetting of sawdust and other agro-residues, have been established in various countries. The inception and development of screw extrusion briquetting technology in Japan in 1945 stand as a testament to the feasibility of this approach (Siahdashti et al., 2022). The notable surge in briquette production in Japan from 1964 to 1969 further attests to the success of this technology. In India, the gradual growth of the briquetting sector is notable, attributed to successful ventures and promotional initiatives by IREDA (Arulkumar et al., 2019). Both national and international agencies are actively funding projects aimed at enhancing the existing briquetting technology in India. Recent achievements in briquetting technology and the increasing number of entrepreneurs entering the sector imply that biomass briquetting holds promise as a viable option for new entrepreneurs and other biomass users (Mythili & Venkatachalam, 2013).

The transformation of residues into a densified form offers numerous advantages. Primarily, it enhances the net calorific value per unit volume, rendering it an efficient and potent fuel source. Furthermore, the densified product's ease of transport and storage makes it a pragmatic solution, particularly for those necessitating transportation over extended distances (Felfli et al., 2011). This method effectively addresses residue disposal concerns, presenting an environmentally-friendly alternative. Ultimately, the resulting fuel exhibits uniform size and quality, establishing it as a dependable option for individuals requiring consistent and reliable outcomes (Chen, Huang, et al., 2009).

Briquetting machines, operating on the principles of the 5Ms framework, offer a multitude of advantages as a renewable energy fuel. These advantages include high burning efficiency, positioning them as a premier substitute source of energy with high density and a superior Fixed Carbon Value (Chen, Xing, et al., 2009). Furthermore, they prove to be environmentally friendly by virtue of being pollution-free, containing no sulfur material, and producing white smoke instead of the environmentally detrimental black smoke emitted by coal. Notably, the cost savings inherent in the use of briquettes compared to coal make them economically viable (Arulkumar et al., 2019). Biomass briquettes exhibit a higher practical thermal value, generate no fly ash during combustion, and their utilization in industries qualifies for Carbon Credits, enhancing their appeal (Yao et al., 2016). With a demandable market driven by the escalating prices of fossil fuels, the localized production of briquettes near consumption centers adds to their attractiveness. Additionally, their lower ash content (2 to 6%) and low moisture content (3 to 6%) compared to coal further underscore their environmental and practical advantages (Osineye et al., 2020). In summary, the comprehensive set of advantages positions briquetting machines as a sustainable and efficient solution for various industries, offering economic, environmental, and practical benefits.

2. Literature Review

(Singh et al., 2007) explored the adaptation of a commercial briquetting machine to produce 35 mm diameter briquettes suitable for gasification and combustion. The research delves into the combustion and gasification behavior of these briquettes. A survey conducted in Gujarat state reveals that most briquetting plants in the region employ a die and punch mechanism, resulting in briquettes of 60 and 90 mm sizes, unsuitable for small-medium gasifiers. This underscores the necessity for biomass briquettes with a smaller diameter. The paper underscores the significance of converting agricultural and agro-industrial residues into high-density, high-value solid fuel briquettes to address the growing demand for wood and mitigate environmental and forest damage.

(Okwu & Emovon, 2018) developed a low-cost, small-capacity, low-pressure, hand-operated briquetting machine to address the energy needs of rural households. Raw materials such as rice husk, dry leaves, groundnut shells, and sawdust, combined with paper pulp as a binding agent, were used to create briquettes. The machine exhibited an average capacity of 5 kg/h. Results indicated a notable increase in biomass bulk density after briquetting—2.3, 2.6, 2.6, and 1.5 times for rice husk, dry leaves, groundnut shells, and sawdust, respectively. Bulk densities were measured at (253.90, 375.40, 265.40, 279.10) kg/m^3, and higher heating values (HHV) were (4000, 3500, 4700, 4500) kcal/kg. Groundnut shell briquettes demonstrated high resistance to shattering, with sawdust briquettes following suit. Briquettes made from dry leaves exhibited notable resistance to water penetration and were found to be satisfactory when used in a local domestic stove with a grate.

(Zhang et al., 2014) explored the performance of a briquetting machine for briquette fuel, utilizing combinations of cashew nut shell, rice husk, and grass as biomass sources. The research compares the applicability of raw biomass, hydrolyzed biomass, and carbonized biomass for briquetted fuel. Various properties of the briquettes are assessed, encompassing calorific value, shattering indices, tumbling test, degree of densification, energy density ratio, resistance to water penetration, and water boiling test. The calorific value is determined using a bomb calorimeter, revealing that briquettes from combination 1 exhibit the highest calorific value, while those from combination 3 have the lowest. Physical characteristics such as length, diameter, weight, volume, and density of the briquettes vary based on the biomass combination. Combination 1 briquettes display the highest degree of densification and energy density ratio, whereas combination 3 briquettes exhibit the least. Additionally, combination 1 briquettes demonstrate favorable properties in terms of shatter resistance, durability, and water absorption, making them suitable for handling, transportation, and domestic fuel use. The study incorporates an economic analysis, calculating the net present value and payback period for each type of briquette.

(Zotero et al., 2016) concentrated on biomass utilization for energy generation as a response to the escalating consumption of fossil fuels and the associated environmental challenges. The study underscores briquetting as a promising recycling method for agricultural residues, transforming loose biomass into value-added products. The selected materials for the briquetting study include pigeon pea stalk, cotton stalk, and soy stalk, with soy stalk briquettes exhibiting the highest gas production. The characteristics of the briquettes, such as higher heating value (HHV) at (4707.88, 4566.90, 4892.64) kcal/kg, bulk densities at (438.70, 641.20, 657.90) kg/m^3, and compressive strength at (1.058, 1.109, 1.083) kN/mm², are obtained. The gasification study highlights the effectiveness of these briquettes for energy generation.

(Romallosa & Hornada, 2011) underscored the necessity of developing a suitable briquetting machine tailored for rural communities, given the inadequacies of existing machines in rural areas, which suffer from low production capacity and subpar briquette quality, relying on manual strength for densification. The widespread adoption of biomass briquettes hinges on factors like residue availability, appropriate technologies, and market demand. However, the frequent failures of briquetting machines in developing nations have impeded their widespread utilization. The study assesses the physical and combustion properties of sawdust briquettes, revealing the significant impact of binder levels on the briquette's physical attributes. The compressed density ranges from 0.6125 to 0.7269 g/cm³, with the highest density achieved at a 25% binder level. The higher heating value (HHV) varies from 27.27 to 29.68 MJ/kg, reaching its peak at a 35% binding agent level.

(Safdar et al., 2020) discovered that briquettes produced from rice husk using the vibratory block mould briquetting machine exhibit a high percentage of volatile matter and a low percentage of ash content, rendering them suitable as biomass fuels. Agro-waste briquettes demonstrate favorable characteristics such as low moisture content, high crushing strength, elevated density (achieved at 1100 kg/m³), slow flame propagation, diminished ash content, increased carbon content, and significant heating value (attained at 15175 kJ/kg). Biomass briquettes, including those from rice husk, present advantages of being cleaner and more manageable than fossil fuels or wood, contributing to the reduction of greenhouse gas emissions.

(Ige et al., 2020) employed agricultural residues, including palm oil mill, sawdust, rice husk, rice bran, and sugarcane leaves, for the production of briquette fuel. Rice husk, being abundant and rich in silica, presents an attractive option for various bio-products. Sawdust, a byproduct of wood processing, is generated in substantial quantities annually. Numerous studies have explored briquette production, encompassing the development of manual, low-pressure, and cost-effective briquette making machines. The performance of briquettes derived from different biomass sources has been assessed, taking into account parameters such as density (highest achieved with 92SD:08RH & 90SD:10RH), moisture content, drop-to-fracture, water resistance, volatile matter, ash content, fixed carbon content, and heating values (highest achieved with 100SD:00RH).

(Pareek et al., 2011) investigated the briquetting process utilizing a thermal-mechanical press machine with a specific mold for briquette production. Various pressures (100, 125, and 150 MPa) were examined to assess their impact on the samples. The process maintained a temperature of 38°C to prevent adhesion mechanisms and extractives' migration. Proximate analysis of the prepared samples was performed using thermogravimetric analysis (TG) to determine moisture, volatile matters (VM), fixed carbon (FC), and ash contents. The high heating value (HHV) was determined according to ASTM standards using an oxygen bomb calorimeter. The pyrolysis process's kinetic study for the briquettes employed a single-step reaction mechanism and the combined kinetics three-parallel-reaction (CK-TPR) model. Iso-conversional methods were employed to estimate the apparent activation energy (E) and the pre-exponential factor (A). Briquettes produced from OMSW mixed with a corn starch binder exhibited enhanced mechanical properties and an increased high heating value (HHV) compared to the raw mixture. Samples with a particle size less than 100 µm and blended with a 15% corn starch binder were identified as promising biofuels for household or industrial use.

(Dantani Abdulmalik et al., 2020) delved into the cost analysis and economic indicators associated with briquette production using piston press technology, specifically focusing on rice straw, rice husk, and cow dung. The study compares the production costs of various briquettes and incorporates the operational costs of power-operated systems for a comprehensive economic analysis. The paper underscores the challenges linked to the direct combustion of loose agro waste residues and emphasizes the advantages of compacting them into briquettes. It highlights how briquettes address issues like low thermal efficiency, fuel loss, and air pollution while simultaneously reducing transportation and storage expenses and improving energy production. The research further delves into the physical, combustion properties, proximate analysis, ultimate analysis, and machine performance of the generated biomass briquettes. The highest heating value (HHV) is observed at 20SD:05RS:40CD, and the bulk density is at its maximum with 10RH:05RS:40CD. The practical application of these briquettes includes substituting coal in industrial processes for heat applications and power generation via gasification.

(Bandara & Kowshayini, 2018) determined that rice husk-based briquettes have emerged as a viable alternative energy source, albeit with low durability attributed to their low bulk density and moisture content. The quality and handling of these briquettes are pivotal for considerations related to storage, transportation, and operation. The utilization of biomass, especially from agro-waste, is regarded as a practical solution to meet energy demands and reduce dependence on non-renewable energy sources.

(Peter Pelumi Ikubanni et al., 2019) stated that the moisture content in blends of rice husk significantly affects the degradation temperature and heating value of the briquettes, with the optimum conditions observed at 14% moisture content. However, briquettes with lower moisture content tend to exhibit reduced durability and higher ash content, potentially leading to equipment failure and increased maintenance costs. Processing variables such as pressure, temperature, particle size, binding ratio, and moisture content exert substantial influence on the overall quality of the briquettes. The highest bulk density is achieved at 12% moisture content, while compressive strength remains consistent throughout the investigated conditions.

Table 1 offers a summary of the literature, presenting valuable information on the physical parameters and proximate analysis of output variables related to densification in the form of briquettes. The table considers various factors, including raw material combinations and binding agents, that could influence the results. Through a careful analysis of this table, a more comprehensive understanding of the effectiveness of densification can be obtained, enabling informed decisions regarding its implementation.

Table 1: Literature Review Summary

S.No.	Raw Material	Binder	Study Outcome			Reference
			Calorific Value (kcal/kg) or HHV	**Compressive Strength(kN/mm²)**	**Bulk density (kg/m³)**	
1	Saw dust	Burnt Engine oil	18.6(MJ/kg)	NA	618	(P. P. Ikubanni et al., 2020)
2	Rice Husk Dry Leaf Groundnut Shell Saw Dust	Paper pulp	4000 3500 4700 4500	NA	253.90 375.40 265.40 279.10	(Ahiduzzaman & Islam, 2013)
3	Cashew nut shell Rice Husk Grass. Combinations- 50:25:25, 25:50:25 and 25:25:50	NA	5154.58 4687.56 4188.64	NA	0.895 g/cc 1.105 1.109	(Sengar et al., 2012)
4	Pigeon pea stalk Cotton stalk Soy stalk	NA	4707.88 4566.90 4892.64	1.058 1.109 1.083	438.70 641.20 657.90	(Ihenyen, 2012)

5	Sawdust 15% binder 25% 35% 45%	cassava starch	29.68 MJ/kg 27.27 33.37 28.85	NA	0.6125 g/cc 0.7269 0.7028 0.6822	(Wang et al., 2015)
6	Rice Husk	Starch	15175 kJ/kg	NA	1100	(Dairo et al., 2018)
7	100SD:00RH 94SD:06RH 92SD:08RH 90SD:10RH	Organic Binder (UF)	27113.38 KJ/kg 26587.18 26058.39 24501.82	NA	820 860 870 870	(Aguko Kabok et al., 2018)
8	OMSW%-Binder% 100-0 90-10 85-15 70-30	Corn Starch	16.36 MJ/kg 16.92	1581 kN 1039 775 626	0.84 kg/dm^3 0.86 0.88 0.84	(Kelly Orhorhoro et al., 2017)
9	Rice Straw, Rice Husk & Saw Dust 10RS:40CD 10RH:05RS:40CD 20SD:05RS:40CD	Cow Dung	2389.86 3188.10 3227.52	NA	170 190 140	
10	Rice Husk having MC 12%	Blended with 10 wt	14.040 MJ/kg	Dia = 40mm t= 9mm 500 kgf	1021 801 644	(Singh et al., 2007)

	14% 16%	% of Kraft Lignin	17.688 13.106	500 500		

Given its status as an agrarian nation, India produces a substantial volume of by-products that may pose environmental threats. The efficient utilization of these premium biomass materials to create solid fuel, known as briquettes, is a crucial imperative. This eco-friendly solution not only holds economic viability but also ensures sustainability. Biomass briquettes can be produced from diverse sources such as dry leaves, wheat straw, sawdust, and other waste materials, providing an environmentally sound alternative (Ihenyen, 2012). Instead of incinerating these materials, which contributes to pollution, adopting a briquetting approach offers a more judicious and eco-conscious handling of waste. The simplicity of the mechanisms involved and the widespread availability of machine elements contribute to lowering fabrication costs, rendering the process economical and portable. This presents a significant opportunity to convert waste materials into a positive resource, thereby contributing to a greener and cleaner environment.

3. Conclusions and Discussions

In developing nations, the abundance of available residue is evident; however, the primary challenge lies in optimizing chemical and mechanical treatments for diverse feedstocks. This challenge becomes particularly pronounced in rural communities where power resources are scarce. In such areas, the most suitable method of pre-processing should involve minimal energy input. Regrettably, the majority of technologies capable of producing high-quality briquettes tend to be expensive and demand substantial energy input. Large-scale production of briquettes requires significant capital investment, posing a considerable barrier to the broader expansion of biomass densification. To attract more investment in regions with limited financial capacity and low energy availability, there is a need to prioritize the development of user-friendly and cost-effective technologies adaptable to various scales. It is essential to acknowledge the existing market for briquettes, recognizing their potential as substitutes for conventional biomass, such as fuelwood, and fossil fuels. However, to fully unlock their benefits, the challenges outlined below must be systematically addressed.

Availability and Quality of Raw Materials: The availability and quality of biomass raw materials can be a challenge for the industry. The quality of the briquettes is directly dependent on the quality of the raw materials used, so it is essential to have a consistent and reliable supply of high-quality biomass.

Cost of Production: The cost of producing biomass briquettes can be higher than the cost of traditional fuels such as coal, especially if the raw materials need to be transported from a long distance. This can make it difficult for the industry to compete in the market.

Lack of Standardization: There is currently no universal standard for biomass briquettes, which can make it difficult for buyers to know what they are purchasing. This can lead to quality control issues and concerns about consistency in performance.

Competition from Other Energy Sources: The biomass briquettes industry faces competition from other renewable energy sources such as solar, wind, and hydroelectric power, which may be seen as more attractive due to their lower cost and ease of use.

Lack of Awareness and Infrastructure: The industry still needs to raise awareness about the benefits of using biomass briquettes as a fuel source. In addition, there is a need for investment in infrastructure such as briquetting machines and storage facilities to support the industry's growth.

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