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Design and Fabrication of an Automated Briquetting Machine for Biomass Replacement in Industrial Process

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Received: 18 May 2026; Revised: 20 June 2026; Accepted: 30 June 2026; Available online: 10 July 2026

Abstract: Sustainable energy demand worldwide is increasing rapidly. There is a significant need for powerful machines capable of converting agricultural waste into solid fuel. This research project aims to design and fabrication of automated briquetting machines for biomass replacement in industrial processes. This machine makes the same-size Firestarter cubes from biomass. The main goal is to develop a low-cost, fully automated briquetting machine. This machine should reduce manpower requirements and produce strong, high-quality briquettes. This machine has four main subsystems. There is a crew conveyor for metal feeding and controlling the material ratios. There is a crusher to crush the materials into small pieces. There is a mixture of adding the binding material and mixing the materials. There is a tank to store the prepared mixture. A piston-driven extrusion system is used for compaction. Operation is controlled by a PLC-based system equipped with sensors, motor drivers, and safety interlocks to ensure accurate sequencing and protect operators. Experimental trials demonstrated that the machine produced uniform briquettes with dimensional variations of ±2%. Biomass has improved mechanical properties, such as torque, shear strength, and compressive strength. These test results show how the briquette machine can deliver an effective combination of mechanical strength, automation, and ease of production. This system can turn farm wastage into valuable fuel. It helps to sustain industries.

Index Terms: Automated briquetting machine, Biomass, Piston extrusion, ESP32 control, Mechanical design, Ratio control system

1 INTRODUCTION

The main power source in the modern world is fossil fuels. Because transportation, Electricity generation, and everything else need fossil fuels. But the problem is that, because of the population and rising demand for people's needs, fossil fuels are not enough to meet those needs. Based on some researchers, the fossil fuel capacity will end in less than 60 years [1]. On the other hand, the use of fossil fuels is not environmentally friendly. It did huge damage [2]. For these reasons, countries, researchers and inventors are beginning to focus on Renewable Energy. They are never end and Environment Friend [3]. Briquetting has traditionally enabled the transformation of agricultural residues into useful fuels for both industrial and domestic use [4].

However, conventional briquetting equipment has inherent problems, including low efficiency, lack of automation, and safety issues. The equipment requires considerable manual effort, lacks proper control, and produces variable quality briquettes. This has resulted in increased production costs and lower market competitiveness due to inadequate automation [5]. The objective of the study is to develop a fully automated briquetting machine, which will address all the issues associated with conventional briquetting equipment by incorporating modern mechanical, electrical, and control components. The proposed equipment will employ an EPS32-based control scheme [6], ensuring precise operation and consistent-quality briquettes. The equipment will be designed with safety and ease of operation in mind, featuring a central control panel. The study also considers the equipment's marketability, an important aspect of the project. The equipment will be designed as a self-contained unit mounted on a mobile stand, facilitating movement and display at exhibitions. The equipment will help create a new market segment by providing an automated briquetting solution, thereby supporting waste utilization and renewable energy development. Generally, this research is applicable to both universal and local issues, including decoupling from fossil fuels, reducing environmental pollution, efficient waste management, and promoting green technology.

2. LITERATURE REVIEW

2.1 Biomass and Renewable Energy

Biomass is the most important renewable energy source used for heating, cooking and industrial processes. Biomass also includes agricultural crop residues, industrial waste, sewage sludge and plant materials [7]. These materials are mostly available in developing countries [7]. We can use this energy for biomass briquettes. A long time ago, biomass was used as fuel. And it is still important in modern energy systems.

Most industries use biomass fuels to make steam in the boilers. Biomass fuels are better than fossil fuels like coal and oil [7]. Fossil fuels produce fewer greenhouse emissions [7]. Renewable energy sources like biomass, hydropower, and biogas are very important [7]. Because of the energy crisis and climate change [7].

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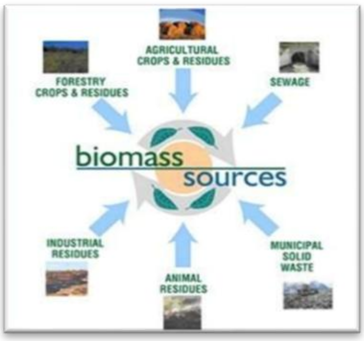

Fig. 1. Biomass Sources Binders

2.1.1 Materials and Methods

Based on the raw material and conversion process, biofuels are categorized into four generations. The first generation of biofuel is made from food crops like sugarcane and oilseeds to produce biodiesel and bioethanol. The first generation of biofuels is produced from food crops such as sugarcane and oilseeds to produce biodiesel and bioethanol [8]. Biomass remnants from the agroforestry and municipal waste industries, including stems, leaves, and bark, are linked to the second generation. These raw elements come from vegetables, and lignin, hemicellulose, and cellulose make up most of their composition [9].

For the manufacture of bioethanol and biodiesel, the third generation includes algae and microalgae with high quantities of total sugars [8]. Bioengineering helps the fourth generation by altering the cellular metabolism of cyanobacteria and algae to increase biofuel production [10]. Briquette production is frequently linked to second-generation biofuels, which encourage the recycling of forestry and agricultural waste. Waste materials, such as stems, bark, leaves, straw, wood, or sawdust, were used in most of the works.

The raw materials used to make briquettes were sourced from a variety of solid waste types, with an emphasis on biomass-based and biodegradable components due to their advantageous physicochemical characteristics for energy recovery. One of the most important sources of biomass for briquetting is agricultural waste. In agrarian economies, materials including rice husk, corn cobs, peanut shells, sugarcane bagasse, coconut husk, and wheat straw are readily available. Because of their high cellulose, hemicellulose, and lignin content, these residues have a higher calorific value and maintain structural integrity when compressed [11]. As a natural binder, lining is particularly essential since it reduces the need for external additives [12]. Utilizing agricultural waste helps address open-field burning, a significant contributor to air pollution in many developing nations, while also providing a sustainable energy source. Another significant type of solid waste considered for briquetting is forestry residues and by-products from the wood processing industry, such as sawdust, wood shavings, bark, and chips. These materials are distinguished by a higher lignin concentration, which increases briquette durability, and a comparatively low ash content compared to agricultural residues. Additionally, they are the perfect feedstock for densification due to their low moisture content and generally homogeneous particle size following mechanical processing. [13], [14]. Paper, cardboard, food scraps, and garden trimmings are among the biodegradable materials included in municipal solid waste (MSW) that can be used as additional feedstock for briquetting. Because of their high carbon and volatile matter content, paper and cardboard can be co-briquetted with other biomass leftovers [15]. However, because MSW is heterogeneous, it must be carefully sorted and pretreated to remove metals, plastics, and other non-biodegradable pollutants that can compromise briquette quality and burning performance. Processing industries produce large amounts of agro-industrial by-products, including cashew nut shells, coffee husks, palm kernel shells, and brewery trash. If these wastes are not properly handled, they can be disposed of carelessly, leading to greenhouse gas emissions during decomposition. Their calorific values are often comparable to traditional wood fuels, and their use in briquette production provides an eco-friendly waste management strategy while diversifying the raw material base [16].

- **Forestry & wood residues** - Sawdust, wood shavings, bark, wood chips.
- **Agricultural residues -** Rice husk, Corn husks, Groundnut shells, Sugarcane bagasse, coconut husks, wheat straw
- **Agro-industrial byproducts -** Coffee husks, Palm kernel shells, Brewery waste
- **Municipal solid waste (Biodegradable fraction) -** Paper, cardboard, food waste, Garden trimmings

Proximate and ultimate studies are required to confirm the basic ingredients used to make briquettes. The proximate analysis provides the durability and potential efficiency of the briquettes produced. To perform the proximate analysis, several physical characteristics of the solid waste must be quantified and assessed, including its total carbon content, volatile matter, fixed carbon, ash content, moisture content, bulk density, particle size, and calorific value. Furthermore, determining the raw material (waste material) used in the briquette production process requires the ultimate analysis. The ultimate analysis weighs the elemental composition of the feedstock, typically carbon, hydrogen, oxygen, nitrogen, and sulfur, that directly relates to emissions of pollutants such as carbon monoxide, fine particulate matter, nitrogen oxides, and sulfur oxides when combusted [17]. To choose the best feedstock, the proximate analysis must be completed before the production process. Like the fuel's nitrogen content, the sulfur ××content of the raw materials is closely correlated with the sulfur dioxide emissions from the feedstock. Consequently, the nitrogen and sulfur content of the feedstock must result in a fire briquette that pollutes the environment less [18].

2.1.2 Material Ratio and Moisture Content

Correct Material Ratio and Moisture Content are the most important factors for producing strong, efficient briquettes. One study shows that moisture content should be between 6% and 16% for better briquettes [15].

- If the moisture content is high, briquettes can break easily and produce smoke when burned [15].
- If the moisture content is low, the materials do not stick together correctly [15].

This study uses formula (1) to calculate moisture content [15].

$$Mc = \frac{\mathrm{Ww} - \mathrm{Wd}}{\mathrm{Ww}} \times 100 \quad (1)$$

- Ww = Weight of wet sample
- Wd = Weight of dry sample

This equation helps to identify the current moisture level of the briquettes.

2.1.3 Material Ratio and Moisture Content

Durability and energy performance are the most important indicators of briquette quality. Briquettes must not break during transport, store or handling [15].

Fig. 2 shows how to check the durability [15]. If briquettes are perfectly produced, they should pass the durability test as follows in Fig. 2 [15].

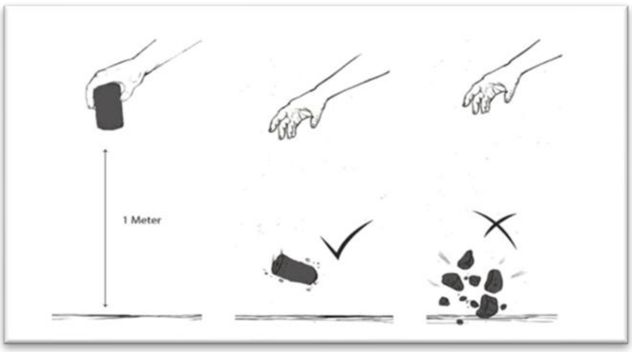

Fig. 2. Testing durability of the briquettes

Another important test is the boiling test. Here, we measure the energy required to boil water. A short boiling time indicates high fuel efficiency and high heat efficiency [15].

2.2 Briquette Durability and Energy Performance

In briquette production, a binder is essential. The quality of the briquette binder also affects the briquette's strength, thermal stability, combustion performance, and cost [19]. Different briquette binders are required for various types of briquettes. The experiment found that the briquette bonding mechanism varies depending on the binder. In general, the following are the qualities a briquette binder must have: strong bonds, pollution-free operation, no impact on coal's heat release or combustibility, no interference with coal use, environmental acceptability, and economic viability [20].

2.2.1 Organic binder

Both the bonding performance and the crush-and-drop test strength of the briquettes made with organic binder are good. However, at high temperatures, the mechanical strength and thermal stability of the briquette made with organic binder are weak, and the binder itself is easily broken down. There are four types of organic binder: biomass binder, petroleum and tar pitch binder, lignosulphonate binder, and polymer binder. A by-product of the paper mill, lignosulphonate primarily consists of sugar, lignin derivatives, organic acids, organic acid salts, free sulfite, and free sodium hydroxide. A lignin derivative can be used as a binder due to its high adhesive strength. The advantages of lignin liquor as a binder are low cost, low ash content, waste utilization, and environmental protection. However, organic materials in liquor would break down and burn at high temperatures, reducing the bonding efficacy. Thus, in actual production, lignosulphonate and an additional binder are mixed to form briquettes. Other additives, such as clay, have been used with lignosulphonate to create briquettes that are less expensive and exhibit good compressive strength [21]. There are numerous benefits to using biomass as a binder, including its broad availability, low cost, and high heating value [22]. A briquette made with this type of binder has a reduced ash percentage, a lower slagging index, and a lower ignition temperature. Thus, biomass as a binder has recently drawn both domestic and international attention [23]. Zhang et al. [24] investigated the use of sodium hydroxide-treated rice straw as a binder for coal briquettes. The maximum crush strength of 244 N/cm^2 and drop test strength of 82.2% were attained by the briquette at a sodium hydroxide content of 2.1%. Polymer binder: Starch is the ideal organic binder because it is a naturally occurring polymer. Although it is often expensive, starch is the most widely used binder. To manufacture the briquettes, 4 - 8% starch is often used. Corn, wheat, maize, rice, cassava, potato, and wheat starch are examples of starch sources. Due to its high cost, poor waterproofing, and poor cooking properties, starch is utilized less frequently in the briquette sector. Modified starches, such as alkaline and gelatinized starches, perform well. Researchers supplemented alkaline starch with other substances to enhance its binding capabilities [25]. Tar pitch and petroleum bitumen binder: These binders, which have chemical properties and structures similar to those of coal, include coal tar pitch, petroleum bitumen, and tar residue. These binders produce briquette-grade agglomerates. When coal solidifies, these binders' great wetting capacity can hold the coal particles together. Nevertheless, these adhesives are usually hot-melt, and their effectiveness degrades rapidly as the temperature rises. Therefore, while using petroleum bitumen and tar pitch as binder, the briquetting process temperature shouldn't be too high [26], [27]. Compound binder: Although briquettes made with an organic binder have high thermal stability, they have lower fixed carbon content and lower combustion efficiency due to the addition of ash. The briquette made with an organic binder has higher volatile strength, lower hot strength, and greater cold strength. The manufacturing procedure and combustion products are also complicated. The benefits of several distinct types of binders are combined in compound binders, which are made up of two or more binders. For instance, the thermal stability and compressive strength of briquettes were improved by adding sodium humate to bentonite and kaolin. Cement, hydrated lime, and polyvinyl alcohol mixtures; humic acid, alumina, and biomass derivative mixtures; and hybrid formulations comprising lignosulphonate, starch derivatives, clays, and resins are among the other compound binders documented. These mixtures enhance briquette quality, making them viable substitutes for traditional industrial fuels [25].

2.2.2 Inorganic binder

Inorganic binders offer several key benefits, including good hydrophilicity, low cost, strong adhesion, and minimal pollution. Typical inorganic briquette binders include clay, lime, plaster, cement, and sodium silicate. The three categories of inorganic binders are environmental protection briquette binders, industrial briquette binders, and civilian briquette binders. Environmental protection briquette inorganic binder: The inorganic binder contains components that can contribute to desulfurization, reducing sulfur dioxide and other pollutants produced during briquette combustion. Numerous studies have demonstrated that certain inorganic binders, such as calcium oxide, magnesium oxide, and iron oxide, can react with sulfur in briquettes to fix it. Lime is the most often utilized binder in environmental protection briquettes. The lime binder-prepared briquette performs well and retains sulfur [25][28]. Industrial briquette inorganic binder: It must have the following qualities.

- Use local resources
- Be inexpensive
- Not produce any pollution

Research has demonstrated that inorganic materials with strong bonding properties, such as magnesium chloride, sodium silicate, and bentonite clay, can serve as industrial briquette binders. This type of binder produces briquettes that are both waterproof and able to withstand harsh environmental conditions. In general, adhesive properties improved as binder content rose [19], [29]. Civilian briquette inorganic binder: The first binders applied to civilian briquettes were lime and clay. When lime is used alone, a significant amount of lime is added, ranging from 25% to 30%, due to its weak cohesive property. The best binder of all clays is bentonite, which is added in small amounts (6-8%). Research indicates that as the amount of organic binder increases, the briquette's burnout ratio varies [30]. When the inorganic binder percentage is less than 15%, the briquette's burn-out ratio decreases slightly as the inorganic binder content increases. Compared to briquettes created with lime binder, those made with clay binder have a slightly greater burn-out ratio. The burn-out ratio of briquettes made with a clay binder has significantly decreased when the inorganic binder percentage exceeds 15%; it is lower than that of briquettes made with a lime binder [30].

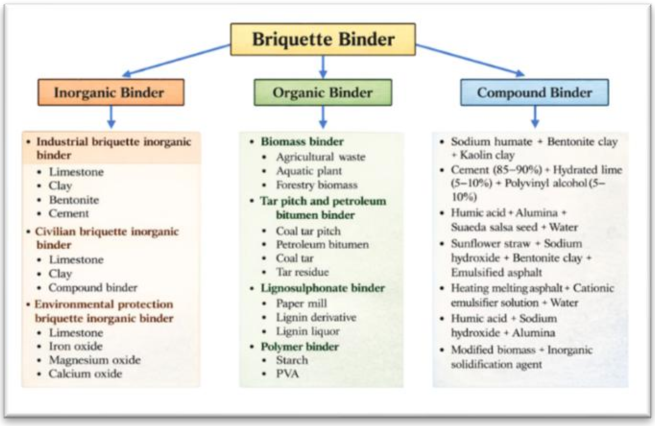

Fig. 3. Types of Briquette Binders

Fig. 3 shows the three main categories of the briquet binders. They are inorganic, organic, and compound binders. Each type is divided into specific sub-types and material compositions used for briquette production.

2.3 Briquetting Process

The manufacture of bio-briquettes does not adhere to a set process. Fig. 4 shows the process of making the briquette. This includes seven main stages from preparation to final transporting.

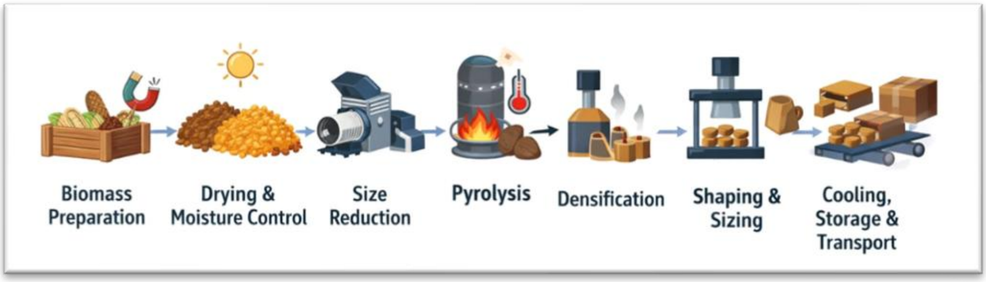

Fig. 4. Process Diagram of Bio-Briquette Production

2.3.1 Biomass Preparation

The first step in briquette production is preparing the raw materials. This includes collecting, cleaning, sorting, and storing biomass before densification [31]. First, the waste is collected and cleaned to remove unwanted materials such as metal pieces, plastic threads, dirt, soil, sand, and stones [31]. These materials can damage the machine, reduce efficiency, and lower briquette quality. After cleaning, the biomass is stored in covered places or sheds [31]. This prevents contamination and allows the materials to dry before further processing.

2.3.2 Drying and Moisture Control

Drying and moisture control are the most important steps. Drying is an essential part of briquetting production, depending on the raw material used [31]. A moisture content of 8-12% is normally ideal for agricultural waste and wood densification [31]. The maximum allowance of moisture content in mechanical piston presses is 15%, whereas hydraulic systems can handle moisture contents up to 15-30 %, depending on the design of the machine [31]. The model used was the Random Piston Type model.

2.3.3 Size Reduction (Chopping / Grinding)

The raw material used in the production of briquettes must be of a suitable particle size before it enters the densification process [31]. The particle size should not exceed 25% of the final product's diameter for most densification equipment [31]. Forest College & Research Institute has briquetting machines with a capacity of 250 kg/hr, producing 30 - 40 mm briquettes, and another capacity of 500 kg/hr, producing 50-60 mm briquettes [31].

2.3.4 Pyrolysis (Optional Thermal Pre-treatment)

Pyrolysis is the process by which biomass is thermally broken down without oxygen at temperatures ranging from medium (300–800 °C) to high (800–1300 °C), yielding solid, liquid, and gaseous compounds [32]. It can be divided into two categories: rapid or flash pyrolysis, which primarily produces liquids and gases, and conventional or slow pyrolysis, which involves carbonization and torrefaction and is mostly used to produce briquettes due to its higher solid output. While carbonization starts at temperatures above 400 °C, torrefaction takes place between 220 and 300 °C [32]. By decreasing the oxygen-to-carbon ratio, improving grindability, increasing energy density by 15–30%, and boosting calorific value from 17–19 MJ/kg to 18–29 MJ/kg, torrefaction enhances biomass characteristics [32]. Torrefied briquettes also become hydrophobic, preserving their energy content and preventing moisture from reabsorbing during storage.

2.3.5 Biner Adding

Binding is the process of adhering biomass material to a specific binder, which is necessary for uniform briquetting and facilitates storage and transportation, reduces mold wear during compaction, enhances the mechanical strength and cohesion of the briquettes, and promotes agglomeration when particles have weak cohesive forces. The properties of the biomass used also affect the binder's impact on briquette quality [19], [20]. However, certain briquetting techniques employ a binder-less approach, meaning that no binder is added. For example, because bagasse naturally contains lignin, Saputra et al. (2020) investigated the manufacture of bio-briquettes from sugarcane bagasse and leaves without the need for additives. A naturally occurring glue-like material found in lignocellulosic plants, lignin serves as a bonding agent for cellulose fibers [19].

2.3.6 Densification

Briquetting, also known as densification, is a technique that uses pressure to compact material, transforming biomass into a denser, more uniform, lower-moisture, and more energy-rich material [31]. The briquette's density after compression determines its overall energy content, thereby increasing its burning rate. Pelletizing, roller presses, screw presses, piston presses, manual presses, and low-pressure briquetting are the five primary press types most frequently employed in densification. Pressers can be divided into two categories based on the pressure applied: low-pressure compaction and high- or medium-pressure compaction [31].

2.3.7 Shaping and Sizing

After compaction, briquettes are produced in various shapes and sizes, depending on the mold and machine [31]. Common briquette shapes are solid cylindrical, cylindrical with a central hole, cubic and prismatic shapes [31].

Briquettes with a central hole can burn very easily. Because this hole increases the surface area and improves air flow during combustion. Small briquettes also burn very fast [31]. Because its area-to-volume ratio is high [31].

One study shows the briquetting unit produces briquettes with sizes of 30-40 mm and 50-60 mm. These values depend on machine capacity [31]. In a Sri Lankan sawdust study, briquettes had a diameter of about 35 mm, and the height changed with the compression level [31]. This information is more important for mold design and size control in automated briquetting systems.

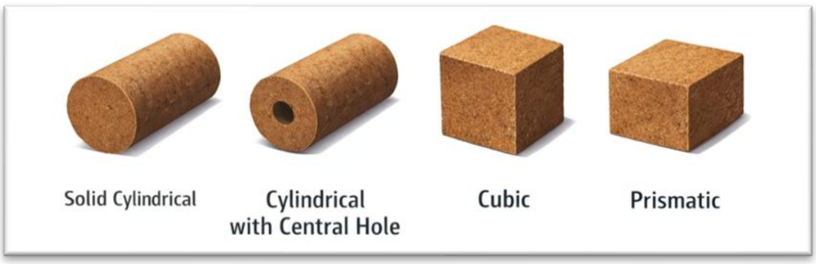

Fig. 5. Different Shapes of Briquettes

Fig. 5 shows different geometric shapes of the briquettes after destination. There are four common shapes. solid cylindrical, cylindrical with a hole, cubic, and prismatic.

2.3.8 Cooling, Storage and Transporting

To allow the briquette to cool optimally, most piston press systems require a cooling track where the material can slowly cool before it falls apart into the desired lengths [31]. After cooling, the briquettes are normally stored before combustion. Storing may take place outdoors under a roof, indoor, in a container or in other ways [31]. The transport from production units to combustion is by truck and tractor.

2.4 Automation and Control Systems in Briquetting Machines

Automation usage improves the efficiency and production capacity of the briquetting machines. In traditional briquetting machines, workers must constantly check the manual operation [33]. But automated briquetting machines use sensors and electronic control systems to operate automatically. This helps to reduce manpower, increase production speed, and improve briquette quality.

According to the Integrated hopper briquetting machines, there are mechanical and electronic components such as motors, sensors, control panels, heating elements, and programmable logic controllers (PLCs) in the new briquette machines [33]. These systems help to control pressure, temperature, and the material feeding process in the machine.

Automation enables the machine to operate continuously with minimal supervision. Automated screw-type briquetting machines use electric motors and control systems to control the speed of the screw shaft. This helps compress biomass properly, improving the density and strength of the briquettes. We can reduce production time using automated systems [33]. One study on an Arduino-based briquette machine shows that an automated system can produce more briquettes in less time than manual machines [33]. So, automation is the most important aspect of modern biomass briquetting technology.

2.4.1 Components of Automation and Control Systems in Briquetting Machines

Automated briquetting machines use mechanical and electronic components to produce briquettes efficiently. The main components include the base frame, feed hopper, barrel, screw shaft, die, motor system, sensors, and control unit [33]. Each part does a specific job in the briquette production process.

The base frame provides structural stability and support for all machine parts. Biomass materials enter the machine's feed hopper. Screw shaft rotates inside the machine and pushes the material to the die to compress it [33]. The die gives the briquettes shape and size [33]. Bearings and transmission systems reduce friction and help transfer power between parts.

In automated machines, control the electronic devices such as sensors, controllers, and motors. For example, the sensors will measure the movement and position of the materials, while the motors will provide the mechanical power to compress the material [33]. The control panels will also help monitor parameters such as temperature, pressure, and speed. This table shows the main components of a briquetting machine system and their functions. The information is taken from a research study.

Table 1. Component part of the WH briquette machine and functions

S/N	Component	Function
1	Base frame	Designed to support briquetting barrel and screw assembly of the system.
2	Feed Hopper	This is a channel for easy passage of feedstock into the screw of the system.
3	Barrel	The barrel was developed into sections and clamped

4	Thrust Bearing	The bearing absorbs a momentous back thrust which compensate for the imparted force directed to the briquette material as it is pulled forward along the length of the screw. The system is designed such that the screw is supported by bearing at the driven end.
5	Die	The extruder has series of shaped holes which allow the briquetting materials to emerge from the machine for easy formation of briquettes. The die holes enable easy formation of shapes of briquettes.
6	Speed reduction gear	With the reduction gear, input speed can be reduced to meet the requirement of slower output speed, while maintaining or increasing the output torque. The pulley drive helps to drive the gear motor of the machine. The pulley is mounted on the motor and the connecting rod shaft so that the power transmission can obtain the desired speed.

2.4.2 Microcontroller and PLC-based Control Systems

The control system works as the brain of the automated briquetting machine. In modern machines, programmable logic controllers (PLCs) or microcontrollers such as Arduino can be used for control systems [34]. These controllers receive signals from sensors and send commands to motors and actuators to control machine operations [34].

In PLC-based systems, the PLC is programmed to control the entire briquetting process. It provides signals from proximity sensors, pressure switches, and other monitoring sensors, as well as PLC inputs. PLC output control devices, such as solenoid valves, motors, and heaters. This integrated system helps to operate automatically and efficiently [34].

In this system, the Arduino serves as the main controller, driving sensors and motors. An infrared proximity sensor identifies the distance between the cutting mechanism and the briquette [34]. Based on this signal, the Arduino activates a servo motor to perform the cutting process automatically [34].

This microcontroller controls the movement and speed of machine parts. This hardware and software combination enhances automation, minimizes manual handling, and enhances production efficiency [34].

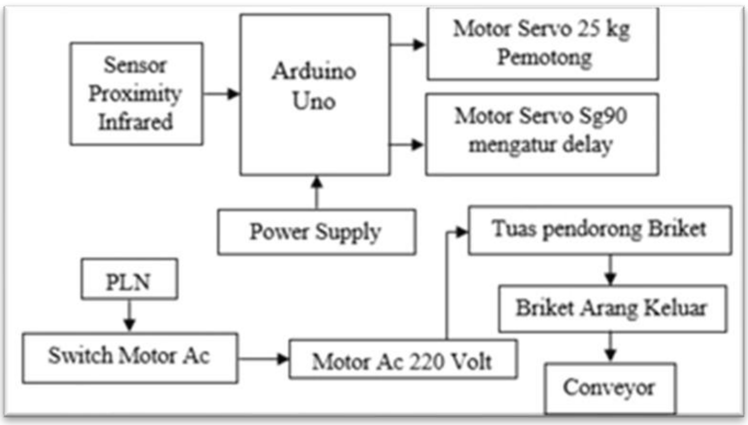

Fig. 6. Block Diagram of Proposed System

As shown in Fig. 6, the automatic briquette printing tool uses the Arduino microcontroller as its main component.

2.4.3 Machine Design Parameters and Equations

To design automated briquetting machines, we need some engineering calculations. These calculations include the dimensions of machine components, belt speed, torque transmission, and power requirements. One Study use equation (2) in here to calculate the area of the machine frame [34].

$$A = \mathrm{L} \times W \qquad (2)$$

- A = Area of the frame
- L = Length of frame
- W = Width of frame

This Study uses equation (3) to calculate speed in the transmission system [34].

$$V = \pi \mathrm{DN}/60 \qquad (3)$$

- V = Belt speed
- D = Pulley diameter
- N = Rotational speed of motor

Another important calculation is the torque calculation [34]. It represents in equation (4).

$$T = (\mathrm{T1} - T2)r \qquad (4)$$

- T = Transmitted torque
- T1 = Tight side belt tension
- T2 = Slack side belt tension
- r = radius of pulley

These equations help engineers determine the optimal machine size and power required to produce briquettes efficiently.

2.4.4 Performance and Production efficiency

The automated briquetting machines have been observed to be more efficient than the manual machines. In the study of the integrated hopper briquette machine, the system's efficiency was observed to be 85%, with the ability to produce 220 kg of material per hour [34].

The Arduino-based automatic briquette machine was also observed to be more productive. In this study, they produced 118 briquettes in 480 seconds [34]. But the manual machine was producing only 43 briquettes at the same time [34]. This shows that automated machines are highly efficient and fast.

All these results show that automated machines are more efficient than manual machines. The results obtained from the automatic briquette-making machine developed in this study were much better than those from manual tool testing, as shown in one research study [34]. The manual briquette-making machine can cut 1 briquette in 30 seconds, 3 in 60 seconds, 6 in 90 seconds, 11 in 90 seconds and 22 in 3 minutes, whereas the proposed automatic coconut-shell briquette-making machine can cut 46 briquettes [34].

Fig. 7 also shows that the quality of briquette pieces produced by the manual briquette molding machine is not as good as that of the automatic machine, with a score of 7 out of 10 [34].

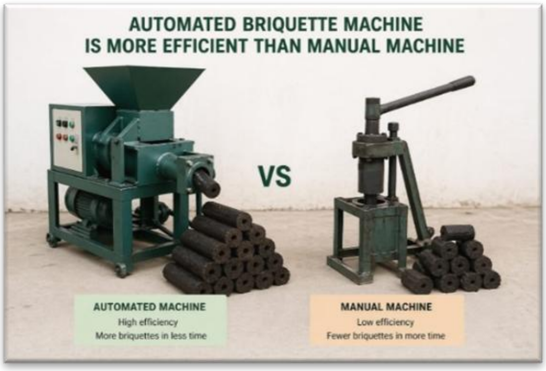

Fig. 7. Automatic briquette making machines and manual briquette making machines

2.5 Machine Design Parameters and Compaction Methods

2.5.1 Machine Types and Mechanisms

There are some machine mechanisms. They are,

- **Screw (Extruder) Press -** A motor rotates a screw that pushes the biomass through a cone-shaped die [35]. This machine operates continuously and maintains constant pressure through the screw. Briquettes are normally solid or hollow cylinders (like a honeycomb) [35]. They are also homogeneous, have a high combustion rate, and do not disintegrate easily [35]. Briquette densities from these machines usually range between 1000 and 1400 kg/m^3 [35]. The biomass should have low moisture to prevent clogging. This machine produces steady output and strong briquettes [35].

  Fig. 8 shows how the screw press briquetting machine works. This figure shows how the feedstock enters the system and is compressed by the conical screw in the nozzle during briquette production.

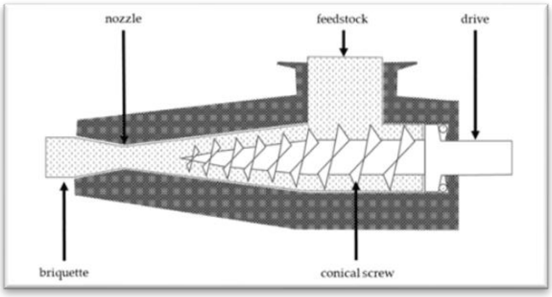

Fig. 8. Screw Press Mechanism

- **Mechanical Piston Press -** The mechanical piston press consists of a ram (piston) and a die, and it is driven by an electric motor [35]. Biomass feedstock is punched into a die by a reciprocating ram under very high compaction pressure to produce a briquette [35]. This machine develops a compression force of approximately 196.1 MPa and is typically used for large-scale production, ranging from 200 to 2500 kg/h [35]. The moisture limit of feedstock is typically 15%; nonetheless, the ideal operating region is 8%- 12% [35]. This uses less energy than the screw press, but it needs strong frames and regular maintenance.

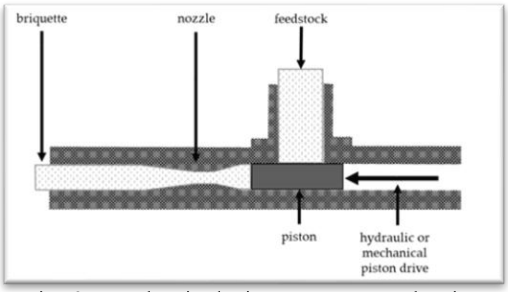

Fig. 9. Mechanical Piston Press Mechanism

Fig. 9 shows how the mechanical piston press mechanism works. The feedstock enters the chamber through the nozzle, where it is compressed by a hydraulic or mechanical piston.

- **Hydraulic Press -** The hydraulic press system works as a piston press. But it Use Hydraulic fluid to move the ram. It usually produces pressures up to 30 MPa (limited by the pump) and has lower output (tens to hundreds of kg/h) [35]. The typical production capacities of these machines range from 50–400 kg/h and can tolerate higher moisture contents than the usually accepted 15% for mechanical piston presses [35]. If the bulk density is less than 1000 kg/m^³, the pressure also reduces [35]. This mechanism helps to make more accurate and stronger briquettes. But it needs pumps and hydraulic fluids. And this mechanism is more complex, and it has slower cycle times.
- **Roller Press -** Roller presses are considered the global standard for producing pillow-shaped briquettes from diverse types of biomass. The feed is pre-loaded and continuously crushed. Typical pressure is very low, and throughput is very high. The roller press works on the principle of pressure and agglomeration. It consists of dual cylindrical rollers of the same diameter, rotating horizontally in opposite directions on parallel axes. The two rollers are arranged so that a small gap exists between them, and the gap distance depends on factors such as biomass type, particle size, moisture content, and the addition of binders [35]. During operation, the raw material is fed into the press and forced through the gap between the rollers on one side. It is then pressed into a die, forming the densified product, which comes out on the opposite side [35]. The smooth production of briquettes with this technology requires high-quality rollers with smooth surfaces for shaping the briquettes [35]. The type of roller or die used determines the shape of the densified biomass, and typical bulk densities range from 450 to 550 kg/m^3 [35].

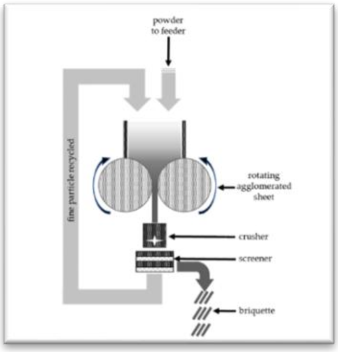

Fig. 10. Roller Press
Mechanism

Fig. 10 shows how the roller press mechanism works. Powder is compressed between rotating rollers, crushed, and screened to produce briquettes.

- **Pelletizer (for comparison) -** The pelletizer machine is not a direct briquetting machine, but it works the same way. It uses a screw system to push the biomass out of the holes and form small pellets. Raw materials should contain 10% to 15% moisture [35]. Also, the size must be less than 4mm. These machines can produce about 5–10 tones per hour [35]. This machine can produce small pellets about 6 mm in diameter using 30-50 MPa pressure [35].
- **Manual Press -** A manual press is a machine that can be operated using hands. It uses a screw or a lever to compress the biomass. It is a low-cost and simple machine [35]. But it gets only small pressure, like 2-5MPa [35]. So, this machine briquettes with low density. Production Speed is very low. It is about 5 kg per hour. The materials should be very fine and dry [35]. It usually needs a strong binder or heat. Normally, a manual press is used for small-scale industries.

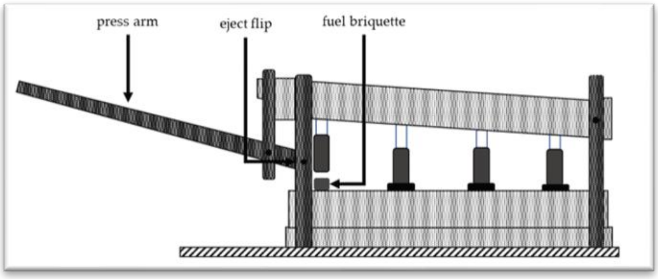

Fig. 11. Manual Pressing Mechanism

Fig. 11 shows how the manual press mechanism works. This shows how the materials are pushed down to shape and how the eject flip removes the finished briquette.

2.5.2 Design Parameters

When designing a biomass briquetting machine, we need to focus on key parameters, including material properties, compaction pressure, moisture content, particle size, and mechanical strength [35]. Design parameters decide the efficiency of briquette production and the quality of the final briquettes. The most important parameters are feedstock properties, compaction conditions, and bonding between biomass particles [35]. During the densification process, particles are pushed closer together using mechanical pressure [35]. So, it creates mechanical interlocking and adhesion forces that bond particles. These bonds help to keep their shape and strength.

2.5.2.1 Feedback properties

a) Moisture Content

Moisture content is a very important property in briquette-making. The correct moisture level helps particles stick together during compaction [35].

- If the moisture content is high, steam can form during compression, preventing proper densification [35]. It can make brick cracks and expansions.
- If the moisture content is low, particles will not blind well [35]. The briquettes break easily.

Different briquetting machines need different moisture ranges.

- Screw press machines require a moisture range of 4–8% [35].
- A piston or hydraulic press needs a 10–15% moisture range [35].
- A hydraulic press sometimes requires a moisture content exceeding 15% [35].

So, most practical studies use a moisture range of 8–12% for briquette production [35]. Lower moisture levels, such as 5–7%, often produce stronger, denser briquettes [35]. However, reducing moisture requires additional energy for drying, increasing production costs.

b) Particle Size, Shape, and Distribution

Particle size is also the most important parameter in the briquette manufacturing process. Small, uniform particles pack tightly during compaction, making briquettes denser and stronger.
Deferent briquetting machines need different particle sizes.

- Screw extruders need 2–6 mm particle sizes [35].
- Piston presses require particle sizes of 6–12 mm [35].

- Pellet production requires particles with a size less than 4 mm [35].

If the particle size is large, there are empty spaces inside the briquettes. These spaces reduce density. It needs more compression pressure to get the same strength. Most systems use 1- 2 mm particles to produce high-quality briquettes [35].

c) Feedstock Composition

Feedstock Composition is the density of loose biomass before compaction. It is also called bulk density. Bulk density of most raw biomass like flakes, chips, or agricultural residues is about 150 kg/m^3 [35]. Low moisture content makes transporting and storing raw biomass inefficient.

All the briquetting systems use pre-compression or densification methods to increase feeding and productivity. It can increase the bulk density to 200–300 kg/m^3. After briquetting, the final briquette density is very high [33]. Normally, briquettes are 5–10 times denser than the original biomass bulk density [35].

d) Ash Content and Calorific Value

Ash content is the material left after biomass is burned that does not burn. For better briquettes, ash contents must be less than 4–6% [35]. If the ash content is high, fuel efficiency is low, and more residue is left. Most biomass has an ash content of 0.5%–10% [35]. These materials are not suitable for briquettes. sludge or charcoal dust [35]. Because they have so much ash content.

Calorific value is the energy released when biomass burns. The calorific value must be 14 MJ/kg to be used as briquette fuel. We can use agricultural waste for this. As the examples [35],

- rice husk - 15 MJ/kg
- bagasse - 17 MJ/kg

2.5.2.2 Compaction Conditions

a) Compaction pressure

Biomass can be densified under high compaction pressure or low compaction pressure. Generally, the feedstock type, moisture content, and particle size and shape determine the required pressure. Densification under low compaction pressure requires a binding agent to enable interparticle bonding. High-pressure densification utilizes the natural binding components such as starch, protein, lignin, and pectin, which are squeezed out of the particles of the biomass materials, to facilitate inter-particle bonding [35]. The outcome of pressure application is plastic and elastic deformations and the filling of voids, resulting in higher-density briquettes. Compaction pressure influences the density, compressive strength, and durability of briquettes [35]. varied pressure from 5.1 to 15.3 MPa to produce briquettes made from wastepaper and Mesua ferrea mixtures at different ratios. The study reported that pressure of 15.3 MPa produced the highest densities for each briquette ratio, while 5.1 MPa produced the lowest. Additionally, in measuring the shear strength of biomass briquettes, the densification pressure from 1 to 10 MPa and found that the shear strength of briquettes increased from 27.5 to 95.7 N (sawdust), 1.2 to 4.6 N (rice husk), 1.3 to 6.7 N (peanut shell), 10 to 73.3 N (coconut fiber), and 10 to 36.2 N (palm fiber someone noted that high pressure helps the densification of biomass and suggests a range of 100–150 MPa, or higher. However, studies have shown that low compaction pressure can yield low-cost, durable briquettes [35].

b) Temperature

Temperature affects both biomass feedstock and the die of the briquetting machine before and during the briquetting process. It aids in the release of components such as lignin, cellulose, and hemicellulose, with lignin acting as a binder [35]. Someone noted that high temperature and pressure are widely agreed to enhance binding mechanisms but require important energy input [35]. One study recommended that the preheating temperature should not exceed 300 ◦C to prevent biomass material decomposition, while the die temperature in a screw press extruder should be kept at about 280–290 ◦C [35]. The study investigated maize cobs briquettes densified at temperatures ranging from 20–80 ◦C. The study concluded that densification at 80 ◦C could produce briquettes with high density and the mechanical strength required to meet quality certification standards. As part of the process parameters for briquetting pine needles, a temperature range of 60–150 ◦C [35] was used. The study found that 150◦C was optimal for producing briquettes. An optimum temperature range of 65–100 °C for feedstock preheating was proposed by someone [35], but they also noted that temperatures up to 300 °C can be used [33]. According to one study, a temperature above the required level will reduce friction between the feedstock and die walls, enabling densification at lower pressure and producing low-quality briquettes. Conversely, low temperatures will result in higher pressure and power consumption. It also leads to a lower production rate but higher-quality briquettes.

2.5.3 Comparative Methods

Comparative Biomass methods are most important to understand their advantages and disadvantages. Screw press, piston press, and hydraulic press mechanisms work under different pressures, moisture contents, and particle contents [35]. These depend on density, strength, and production efficiency. When comparing methods, we can choose the best machine for industrial use.

Table 2. Comparative methods

Mechanism	Pressure Range	Throughput	Briquette Density	Note
Screw Press	5-20MPa (Continuous)	0.5-1t/h	1000-14000 kg/m^3	Central-hole cylinders,
Mechanical Piston	50-200MPa (Reciprocating)	0.2-2.5t/h	1000-1200 kg/m^3	Solid cylinders
Hydraulic press	≤30MPa	0.05-0.4t/h	<1000 kg/m^3	Small cylinders.
Roller Press	2-10MPa	(tons/h, very high)	450-550 kg/m^3	Pillow briquettes
Manul Press	≤5MPa	0.005t/h	(low density)	Extremely low capacity

This table compares these five mechanisms.

2.5.4 Design Parameters for Automated System

Briquetting machine frames must be strong and rigid. Because it gets high pressure during compaction. Main frames are made with mild steel. Mild steel is very strong and more durable [35]. Components that are subject to biomass or heavy loads should be made of hardened steel or wear-resistant plates. Bearings, bushings, and lubrication points are used to reduce friction and withstand heavy forces during machine operation [35].

The compact chamber or die is a significant component of the machine. The die design may be cylindrical or prismatic, depending on the required briquette shape. The inner surface of the die should be smooth to minimize friction and ensure better briquette quality [35]. A conical entry facilitates the easy flow of material into the die. If hollow briquettes are required, a mandrel can be employed to create a hole in the middle [35].

The compression mechanism is responsible for the force required to produce briquettes. In screw press machines, a screw with a rotational motion compresses the biomass inside the chamber. In piston presses, a hydraulic or mechanical ram exerts high pressure to compact the material. The compaction force can be calculated using the equation (5) given below [35].

$$P = \frac{\mathrm{F}}{\mathrm{A}} \qquad (5)$$

- P = Pressure
- F = Applied Force
- A = Area of the die

These machines must include a feed system, such as a hopper and a screw feeder, to continuously supply the biomass. We need to keep the particle size between 4 and 10 mm using a grinder or chopper before feeding [35].

Moisture control is also a very important parameter for automated systems. Biomass should be dried to less than 15% moisture before briquetting [35]. Therefore, the particles bind together better. Also, it helps to get strong briquettes.

We can use Sensors and control systems to monitor important parameters such as pressure, temperature, and moisture content. Also, it must include safety devices like a pressure gauge and emergency stop switches [35]. After compaction, the briquettes may need cooling and drying before storage. We can achieve an end moisture content of 5% [35].

2.6 Die Pressure Modeling

It is very important to understand the pressure to optimize the briquetting process. Orisaleye [1] presented mathematical models that helped understand the die pressure in screw briquetting machines. This study helped understand the parameters that affect die pressure and optimize them to achieve high-quality briquettes.

2.6.1 Mathematical Modeling for Die Pressure

When calculating the die pressure, the compacted biomass is assumed to flow through the die like a plug. There are several assumptions.

- Coulomb friction is between biomass and the die [36].

- Slipping happens where the material touches the die [36].
- Friction does not depend on pressure or temperature [36].
- Pressure inside the plug is not isotropic for all directions, and strain hardening is ignored [36].

Total Die pressure is divided into two main parts. They are [36],

- Die entry pressure (conical section)
- Briquetting die pressure (cylindrical section)

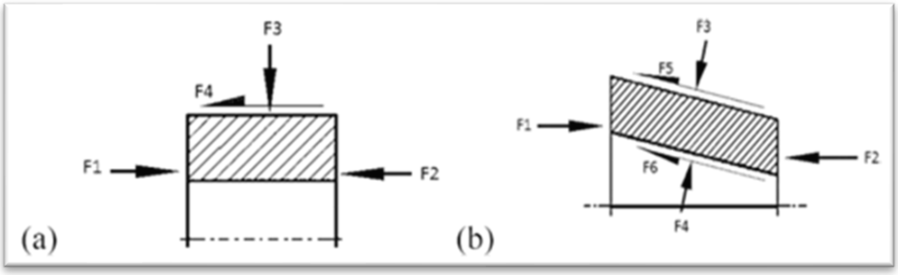

Fig. 12. (a) Forces acting on the plug of material flowing through the briquetting die;(b) Forces acting on the elemental slice of material flowing through the conical die entry.

Fig. 12 shows the forces acting on biomass material inside a briquetting die. a) shows Forces acting on the plug of material flowing through the briquetting die, and b) shows Forces acting on the elemental slice of material flowing through the conical die entry [37].

2.7 Mobility and Transportability of Briquetting Machines

Mobility and transportability are important for briquetting machines. A mobile machine can be moved easily from one place to another without affecting its strength or performance. This is useful for demonstrations, exhibitions, and field work where the machine needs to be moved often [38]. The design should reduce weight but keep the machine strong and durable. Wheels or trolley systems are often added to the frame so operators can move the machine easily while keeping it stable.

2.7.1 Portable Briquetting Machines

Portable briquetting machines are small, and they can be easily moved from one place to another. An example is the Biomass Mini-Mobile system, which produces straw briquettes [38]. These machines combine many parts into one portable unit. The main advantage is that they can be used directly on farms or agricultural sites [38]. This saves money on transporting raw biomass and makes briquette production more efficient.

Portable machines are very useful in rural areas with limited energy and industrial facilities. Even small machines can produce enough briquettes for home use or small industries.

2.7.2 Structural Design Suitable for Mobility

The briquetting machine's design also influences its mobility. Normally, standard briquetting machines include components such as a hopper, a motor, grinder blades, a sieve box, mixing blades, a cylinder, a piston, bearings, and a frame [38]. These components must be made compact. It is easy to move. Machine frames use a stable base and strong materials to make transportation easier [38].

The use of standard machine components also reduces the machine's cost and makes it portable. The machine can thus function effectively in different places.

3 RESEARCH GAPS

Existing briquetting machines have some problems. Most systems did not improve automation, optimization and some other qualities.

- **Material-Specific Adaptability**-

  Most existing briquette machines operate only on biomass. Therefore, flexible machines capable of handling various types of biomass are needed.
- **Energy Efficiency** -
  Automation increases process efficiency but may also increase energy consumption. Improving energy efficiency is very important for automated briquetting machines.
- **Cost-Effectiveness**
  Automation increases process efficiency but may also increase energy consumption. Improving energy efficiency is very important for automated briquetting machines.

These gaps show a strong need for a fully automated briquette manufacturing system. If we can reduce these problems, we can increase production speed, increase production quality, reduce human errors and protect the system.

4 DISCUSSION

The literature review indicates that biomass briquetting is a viable, sustainable technology for converting agricultural and biodegradable wastes into useful energy. Many researchers have proven that biomass briquettes can be used to reduce the consumption of fossil fuels and manage waste. Materials such as sawdust, rice husk, bagasse, coconut husk, coffee husk, and many other agricultural wastes can be used to make briquettes. Therefore, briquetting can be very useful, especially in developing countries like Sri Lanka.

The quality of briquettes also depends on various factors, like moisture content, particle size, binder, pressure, and the machine used for briquetting. It should also be ensured that the particles are smaller, as this will make the briquettes stronger and denser. It should be noted that the binder must also be carefully selected, as it can significantly affect durability and production costs. However, some materials can be briquetted without the addition of binders, as they contain lignin.

The various briquetting machines have different advantages. Screw presses provide continuous operation and dense briquettes but require low moisture and more power. Mechanical piston presses provide high pressure and production rates suitable for industry. Hydraulic presses require more moisture but offer better control and faster operation. The selection of briquetting machines depends on briquette quality, cost, and energy use.

The use of automation enhances the performance of briquetting machines. Sensors, PLCs, and microcontrollers enhance the accuracy of feeding machines, control compactness, and provide labor savings. Automated briquetting machines produce more briquettes, provide safety, and ensure quality. However, existing machines are costly, consume more energy, and are limited to certain biomass types. There is still room for developing cost-effective, energy-efficient, and flexible automated briquetting machines.

Overall, this research provides guidelines for the design of automated briquetting machines. A good machine should be equipped with proper biomass preparation, moisture control, pressure control, mechanical components, and automation. Considering all these factors can lead to the design of efficient, affordable, and useful machines, whether for industrial or domestic purposes. This, in essence, achieves the purpose of this research: to design an automated briquetting machine that is affordable, efficient, and capable of producing high-quality briquettes with minimal human labor and maximum safety.

5 CONCLUSION

The design and Fabrication of automated biomass briquetting machines are very important for the development of sustainable energy technologies. Also, waste management technologies. This research provides clear solutions for the efficient management of agricultural waste. This provides environmentally friendly and highly efficient solutions for the use of fossil fuels. This research provides highly efficient solutions for the use of fossil fuels. This research is helping to reduce the import of fossil fuels. The objectives of this research are to design, simulate, fabricate, and test a briquetting machine that achieves the same quality and high density. This machine is helping to reduce labor costs. This machine provides accurate mechanical design, automated control, and some principles to design the high-quality briquettes. This machine uses fossil fuels efficiently. This research provides efficient use of fossil fuels. This research is helping to reduce the import of fossil fuels. This research provides clear solutions for the efficient management of agricultural waste. This research provides clear solutions for the efficient management of agricultural waste. This research provides clear solutions for the efficient management of agricultural waste. These objectives provide technological, environmental, economic, and social benefits. This machine helps to utilize the waste energy to produce fossil fuels. This machine helps reduce carbon emissions. This machine helps to use renewable energy. This machine provides market opportunities for small-scale industries and farmers. This research provides clear solutions for designing the automated briquetting machine in the future. This research is both highly practical and highly important to society. This machine provides accurate mechanical design, automated control, and some principles to design the high-quality briquettes. This research promotes the efficient use of fossil fuels, sustainable energy practices and renewable energy. This research provides a clear foundation to utilize agricultural waste as a source of energy. This research provides a clear foundation to utilize agricultural waste as a source of energy.

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