Development and Performance Evaluation of a Hydraulic Operated Double Mould Briquette Machine

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Osei, I., Mwinisin, P., McEben-Nornormey, R.M.A., Larbi, K. and Ayisi-Kwofie, A. (2022), “Development and Performance Evaluation of a Hydraulic Operated Briquette Machine” *Proceedings of the 7th UMaT Biennial International Mining and Mineral Conference, Tarkwa, Ghana*. pp. 1- 11

Abstract

Briquetting is a method of mechanically compacting bulky materials to increase their densities. Imported briquette machines are expensive, need technical expertise, lack spare parts, and require electricity for operation. A hydraulic-operated double mould briquetting machine was successfully developed in this study. The biomass briquetting machine is designed for small-scale biomass briquette manufacturing. A 2-ton-sized hydraulic jack is used to provide two equal but opposite pressures for the production of briquettes from two sets of mould boxes. The developed briquette machine was used in the production of sawdust briquettes which were subjected to shatter index and water resistance tests. The physical properties of the briquettes produced were determined at varying biomass-binder ratios of 100:15 and 100:25 by weight using cassava starch as the binding agent. The developed briquette machine consists of two mould boxes positioned vertically opposite to each other at the top and the bottom. Each mould box has 16 set of pistons which aid in the compaction process giving the machine the capacity to produce 32 briquettes at a time. The shatter index and water resistance capacity of the produced briquettes were determined to be 98.6 % and 95.75 % respectively and were attained at an optimum biomass-binder ratio of 100:25. The analysis or tests performed on the briquette from saw dust demonstrate that the machine's performance is good.

Keywords: Briquettes, sawdust, hydraulic jack, piston

1 Introduction

Energy plays a siginifcant role in the development of every nation. It is one of the main drivers of socio-economic development. Many developing countries especially those in sub-Saharan Africa (SSA) are faced with several problems of which access to energy can play a significant role in solving them. Biomass which is the renewable organic material that comes from plants and animals sorces continues to be an important fuel in many countries, especially for cooking and heating in developing countries. On average, in the industrialised countries biomass contributes less than 10% to the total energy supplies, but in developing countries the proportion is as high as 20-30%. In a number of countries particularly in Sub-sharan African countries biomass supplies 50-90% of the total energy demand (Anon., 2007) The world is covered in a significant amount of biomass. The total biomass on the planet is estimated to be over 1 800 billion tonnes. The amount of agricultural biomass produced each year is estimated to be around 140 billion tons globally (Chandak *et al.*, 2015). This amount of biomass has the potential to produce a huge amount of energy and raw materials. However, the traditional use of biomass resources such as woodfuel presents associated environmental challenges particularly deforestation and corresponding contribution to climate change. Moreover, it has been estimated that cooking with traditional use of biomass, coal or kerosene causes 2.5 million premature deaths annually, slowing development and entrenching gender inequality (Anon. 2021). The use of low density lignocellulosic biomass waste such as agricultural and wood residues can be used in place of the firewood and charcoal.

Agricultural and wood processing waste have an enticing raw material potential for both large-scale companies and small-scale businesses. Residual stalks, straw, leaves, roots, husk, nut or seed shells, and animal husbandry waste are examples of agricultural waste (Sharma *et al.*, 2020). Wood processing wastes include; wood chips, offcuts, waste timber and sawdust (Dinesha *et al*., 2019). Agricultural waste is a valuable resource since it is abundant, renewable, and almost free. Countries are currently seeking for alternative energy sources to minimize greenhouse gas (GHG) emissions as part of an international push to combat climate change (Bhutto *et al.*, 2011). Aside from being carbon neutral, using biomass for energy decreases reliance on fossil fuel consumption, thereby helping energy security and climate change mitigation (Anon., 2009). Rapid increase in volume of agricultural and wood waste as a result of intensive agriculture in the wake of population growth and improved living standards is becoming a growing problem. The environmental impact of agricultural waste is determined not only by the amount produced but also by the disposal methods used. Some of the disposal methods are harmful to the environment. As a result, inefficient agricultural biomass management contributes to climate change, water and soil contamination, and local air pollution (Amanor, 2014). Particulalry in Ghana, field and process agricultutal and wood residues such as rice husk sawdust are openly burnt contributing to local and global climate change (Osei *et al*., 2021). The agriculture industry generates 1 300 million tonnes of solid waste per year worldwide . This figure is expected to increase as agricultural product demand rises (Amran *et al.*, 2021). In Ghana, in terms of total residues, Osei *et al.* (2021) reported that, the Northern (3 780 136 t/yr), Brong-Ahafo (3 647 669 t/yr), and Eastern regions (2 943 424 t/yr) produce significant quantities of crop residues. Rice husk, oil palm, and cassava peel residues were identified as key agricultural residue categories that are underutilized and therefore suitable for energy generation. Kemausuor *et al.* (2014) have also reported similar crop residues availability for energy production.

Eventhough there is a growing tendency toward converting agricultural and wood waste residues to environmentally benign sources of energy most of the rfesidues are underutilized, with much of it being left to rot or openly burned in fields, particularly in developing nations with weak rules to regulate such pollutive practices (Abdullah *et al.*, 2021). The use of biochemical (microbial fuel cell and biogas) and thermochemical (direct combustion, pyrolysis and gasification) conversion technologies have often been used to convert these residues to various energy sources. Among the conversion technologies, direct combustion of is a frequent alternative practice that pollutes the air, endangering human and environmental health (Roy *et al*., 2012). Few of the residues generated in Ghana are used for heat, steam and electricity generation in medium and large scale wood and agroprocessing companies (Osei *et al*., 2021). Underutlisation of these resources particularly in Ghana and other developing countries despite lack of energy and climate change is mainly as a result of lack of tailor made efficient and easy to use conversion technologies (Osei *et al*., 2021). Morever, one of the main challenge of using these biomass residue types is the low bulk density which affects the burning characterisitics and effectiveness for cooking and heat applications (Bhoumick *et al.*, 2016). Densification of these residues types is therefore essential for it efficient usage. This can howver be solve through the production of briquette.

Biomass briquetting is the process of compacting loose biomass material to generate compressing solid composites of various sizes by applying pressure, heat, and a binding agent to the loose components (Bhoumick *et al.*, 2016). The majority of individuals in rural areas are farmers who rely on wood fuel for all of their residential and other heating needs, the production of briquette can direct;y replace woodfuel cnd charlcoal reducing the dependency on these traditional fuel sources (Mwampamba *et al.*, 2013). Although several briquetting technologies have been developed, only a small quantity of biomass is used particularly in Ghana and other developing countries. The use of agricultural and wood waste residues for briquette production have been investigated by a number of studies (Antwi-Boasiako and Acheampong, 2016; Ajimotokan *et al.*, 2019; Orisaleye *et al.*, 2019; Njenga *et al.*, 2013). Among the various agricultural and wood processing waste, sawdust is one of the readily available feedstock that can be used for briquette production in Ghana. It is one of the most intensively used feedstock for briquette production (Antwi-Boasiako and Acheampong, 2016). Wood briquettes made from sawdust particles and wood chip leftovers are a particularly clean source of energy. The commercialization of wood pellets/briquettes may be conceivable in the forest-rich southern part of the country (Mohammed *et al.*, 2013). The use of agriculture and wood waste for briquette production as an alternative energy source depends on three factors; the availability of residues, efficient simple briquette machine and the market for briquettes (Ohene-Akoto *et al.*, 2021).

The physical chemical properties of briquette as well as sustainable production and utilisation of briquettes is dependent on the type, availability and efficiency of the briquette machine (Amanor, 2014). The screw press and piston press are two technologies for producing briquette (Shakya and Leon, 2022) (see Figure 1). Many people lack access to these technologies particularly in Ghana because, for example, spare parts for the screw press briquette machine are expensive, it is difficult to maintain, and it takes a high level of technical knowledge to run. The piston press briquette machine requires electrical power and may be difficult to use in unelectrified rural communities. Moreover, these machines are heavy making it difficult to move; and it is expensive, making it impossible for many people in rural regions to afford (Amanor, 2014).

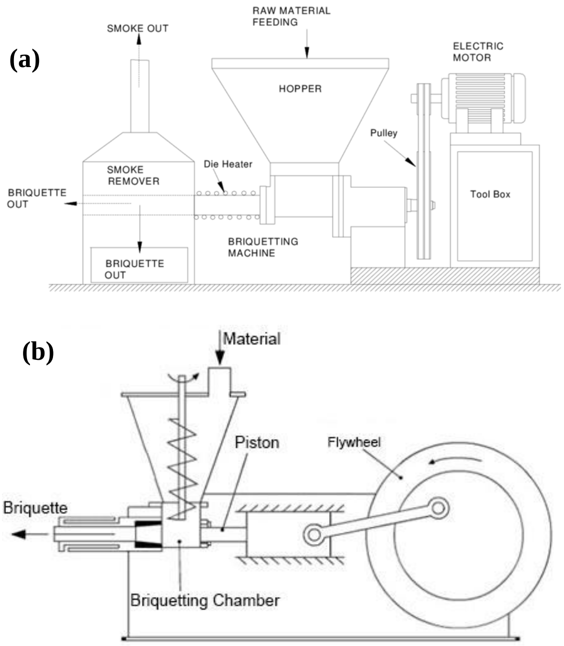

Figure 1 Briquette Machine Technologies. (a) screw-press type briquette machine (b) piston-press type briquette machine.
(Shakya and Leon, 2022)

Moreover, a number of studies have reported the development of different briquette machines. Using locally accessible resources, a 10-tonne agro-waste manual briquetting machine was developed and built by Ihenyen and Osarenmwinda (2012). The frame, compaction chamber, and base plate are the main components of the machine. Its compaction chamber is composed of twenty (20) moulding dies, each with a transmission rod, piston, and ejector. This machine can produce only 20 briquettes at a time. Fadeyibi and Adebayo, (2021) developed, built, and tested a dually operated screw press for the manufacturing of briquettes from agricultural leftovers. The efficiency of the machine increased as residence time increased, whereas the capacity declined as the resident time of machine operation increased. Their machine can be operated either in the monitoring mode (using electricity) or manual mode. It is paramount to understand that the potential end-users of briquetting machines are low-income earners with low educational background, therefore any designed briquette machine should fulfill its purpose as well as be as simple as possible. Therefore, for agricultural and wood waste residues to have a significant influence as a source of energy for communities, it is critical that an efficient and simple-to-use technology be developed expressly for them (Amanor, 2014). There are still significant gaps to be addressed, particularly with regards to developing simple but efficient briquette machine. The aim of this study is therefore to develop a double mould briquette machine utilisng agro and wood waste. The specific objectives this study therefore aims to achieve are;

i. Design and construct a hydraulic operated double mould briquette machine
ii. Evaluate the quality of briquettes produced by the machine using shatter index and water resistance test.

The creation of an adequate briquetting machine acceptable for the communities is currently required in the densification of these agricultural wastes in developing countries particularly Ghana. The outcome of this study is essential for stakeholders particularly technologist, research institutions and entrepreneurs within the renewable energy space. This study is also in line with government of Ghana's efforts to develop bioenergy conversion technologies as part of the renewable energy masterplan (Anon., 2019).

2 Resources and Methods Used

The study employs a multi-stage process involving the design and construction of a hydraulic operated briquetting machine and subsequent production and testing of sawdust briquettes. The processes employed during this study are shown in Figure 2

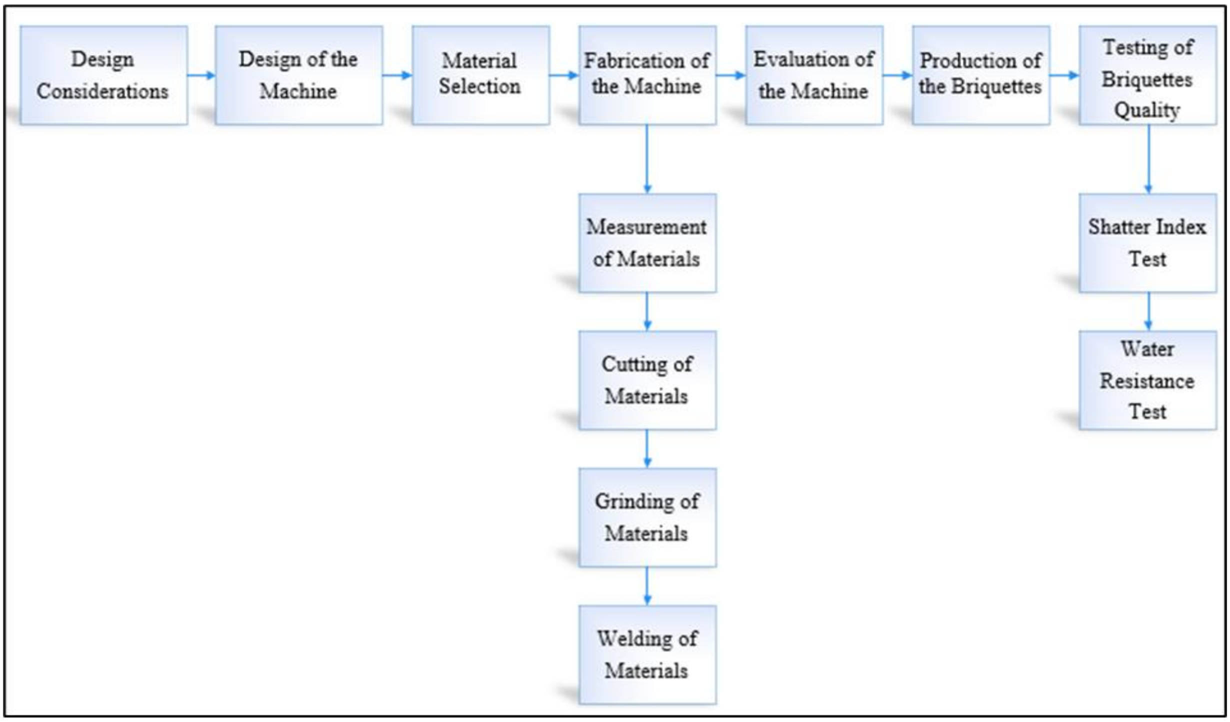

Figure 2 Flow diagram of the Methods Employed in designing the Briquette Machine

2.1 Conceptual and Proposed Designs of the briquette machine

2.1.1 Conceptual Design

The conceptual design on which the manual briquetting machine was developed was proposed by Amanor (2014) (see Figure 3). This design employed a hydraulic jack for the compaction work. It is operated by a set of pistons pressing the biomass material in a mould box producing twenty-five briquettes at a time. The proposed design emphasized on these concepts and some modifications were made to improve functionality.

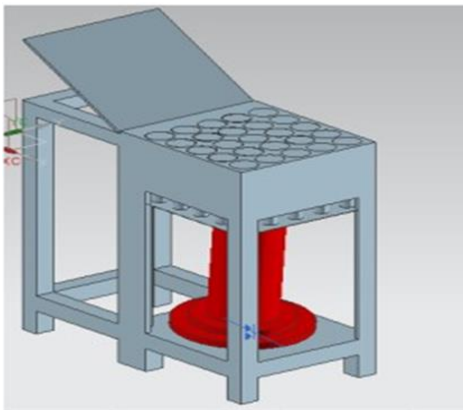

Figure 3 Design 1
(Source: Amanor, 2014)

2.1.2 Proposed Design

The dual-molded hydraulic briquetting machine was developed based on the conceptual designs in this study as shown in Figure 4. The proposed design component includes two piston sets, each consisting of 16 pistons welded together, two mould boxes, the machine frame and a hydraulic jack.

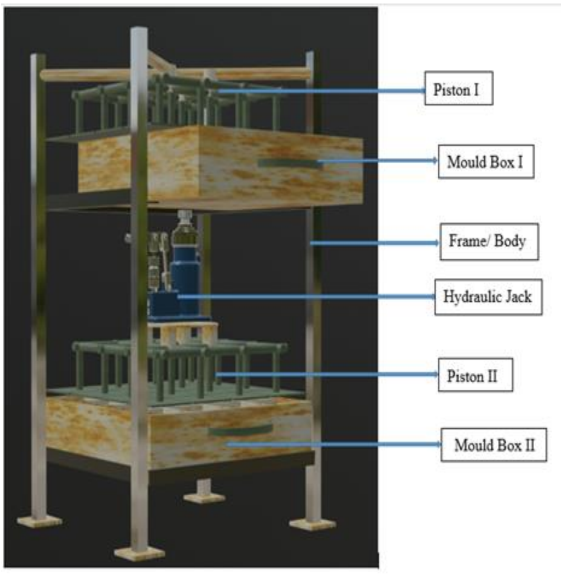

Figure 4 Proposed Design

2.1.3 Principle of Operation of Proposed Design

The briquette machine works on the principle of Newton's third law of motion (ie. For every action there is an equal and opposite reaction) . The force exerted by the hydraulic jack compresses the mould at the top and the pistons at the bottom simultaneously. The proposed design produces two batches of 16 pieces of briquettes per operation as opposed to the conventional one batch process as designed by Amanor (2014).

2.2 Selection of Hydraulic Jack

The manual briquetting machine was designed to produce thirty-two (32) briquettes at a time. The following equations were used to select a hydraulic jack used to lift the machine components and compress the briquettes.

$$A_C = L \times B \qquad (1)$$

where A_C (m^2) = total area on which pressure acts;

L (m) = length of the mould; and
B (m) = breadth of the mould.

Total mass of briquette samples,

$$M_T = N \times M_W \qquad (2)$$

where, N = number of briquette samples;
$M_W(kg)$ = mass of one briquette sample;
$M_T(kg)$ = total mass of briquette samples.

The total weight to be lifted by the briquette machine (W_J)was therefore estimated using Equation 3.

$$W_J = \left(M_T + M_{MT} + (M_{TR} \times 16)\right) \times g \qquad (3)$$

where $M_{TR}(kg)$ = mass of one transmission rods;
$M_{MT}(kg)$ = Total mass of the mould box at the top.
g = acceleration due to gravity = 9.81 m/s^2

Pressure of load to be carried by the hydraulic jack P_J (N/m^2) is given by equation (4):

$$P_J = \frac{W_J}{A_C} \qquad (4)$$

Pressure to be exerted by the hydraulic jack to produce the briquettes (P_T) is given by equation (5).

$$P_T = P_C + P_J \qquad (5)$$

where, P_c (N/m^2) = optimal compaction pressure force for sawdust briquettes. The optimal compaction pressure for small scale briquette production of 6.89 MN/m^2 as reported by Essien *et al.* (2020) was used in this study.

The total compaction force (F_T) required to produced the briquette is given by equation (6).

$$F_T = P_T \times A_C \qquad (6)$$

where, F_T (N) = Compaction Force.

The capacity of the hydraulic jack was therefore selected based on the total mass (m) required to be overcome in order to compact the briquette (see equation 7)

$$m = \frac{F_T}{g} \qquad (7)$$

2.3 Material Selection and Machine Construction

The materials used in the construction of the briquetting machine are listed as follows:

1. 3 mm Mild Steel Plate;
2. 5 tonne Hydraulic Jack;
3. Cutting Disk;
4. Grinding Disk;
5. Welding Electrodes;
6. 20 mm x 20 mm Square Steel Bar;
7. 2 mm Angle Iron; and
8. 16 mm iron rod.

The six parts of dual-moulded briquetting were designed and fabricated individually. The fabrication of the various parts of the machine was done at the Mechanical Engineering laboratory of the University of Mines and Technology, Tarkwa. The materials used for the construction of the various parts of the proposed design and their corresponding dimensions are given in Table 1.

Table 1 Design Specifications

Section/Part	Dimension (mm)	Material
Body/Frame	110 x 20 x 20	Square Steel Bar
Mould Boxes	40 × 10 x 30	Mild Steel Plate
Pistons	11 x 16	Iron rod
Mould Box Handle	20 x 16	Iron rod

Based on the masses of the components of the machine and the optimal compaction force for sawdust briquetting, a hydraulic jack was selected.

2.4 Briquette Production and Quality Testing

The performance of the briquette machine was assessed by the quality of briquettes produced (Ikubanni *et al.*, 2019). The briquette quality testing method employed for this study is the shatter index and water resistance test. The briquettes were produced using the following materials:

1. Sawdust;
2. Water; and
3. Cassava starch.

2.4.1 Briquettes Production Process

The sawdust briquettes were produced using the following steps as reported by Njenga (2014):

1. Dry sawdust was obtained from a sawmill in Tarkwa;
2. The sawdust was then sieved using a 1 mm sieve to remove foreign materials from the raw material;
3. Cassava starch was used as the binder due to its availability. Two sawdust to binder ratios were used to ascertain the optimal binder ratios for the developed briquettes. A binder ratio of 100:25 and 100:15 by mass were used as suggested by Amanor, (2014);
4. The sawdust was mixed with water and the cassava starch.
5. The mixture was loaded into the mould boxes and compacted using the hydraulic jack.
6. The briquettes were extruded from the mould boxes and air dried for three days.

2.4.2 Briquette Quality Testing I (Shatter Index)

The Shatter Index test is a specialized test used to assess the behavior of moulded objects under dynamic stresses (Bala and Olabisi, 2017; Rajaseenivasan *et al.*, 2016). In this study the briquettes were dropped from a height of one meter onto a solid floor. The weight of the crumbled briquette was recorded. Equation (8) was then used to determine the shatter index. The experiment was repeated three times and average values were used.

$$Percentage\ weight\ loss = \frac{W_1 - W_2}{W_1} \times 100\% \quad (9)$$

where;
W_1 (kg)= weight of the briquette before shattering.
W_2 (kg) = weight of the briquette after shattering.

A low percentage of weight loss implies the briquette is hard, more breakage resistant and of high quality.

2.5.3 Briquette Quality Testing II (Water Resistance Test)

This test helps to determine how the briquettes are going to react or behave during rainy seasons or when they are in contact with water (Rajaseenivasan *et al.*, 2016). The briquette was immersed in water maintained at the atmo-spheric temperature and pressure for 30 s to determine the percentage of water resistance to penetration. The percentage of water that has entered was then calculated using Equation 9. The value of water resistance should be higher in order to ensure the strength of the briquettes. The experiment was repeated three times and the average values were used.

$$Percentage\ water\ gained\ by\ the\ briquette = \frac{W_2 - W_1}{W_1} \times 100\% \quad (9)$$

where;
W_1 = the initial weight of the briquette
W_2 = the final weight of the briquette after being immersed in water

Water resistance capacity = 100 - % of water gained by the briquette.

The lower the amount of water absorbed by the briquettes, the greater its ability to withstand water.

3 Results and Discussion

3.1 Briquette Machine Design and Fabrication

3.1.1 Design and Construction of the Mould Box

The mould box contains 16 moulds, each 10 mm in length and 10 mm in width. The moulds were cut with a cutting disc and grounded using a grinding disc to ensure a uniform and levelled height. The mould box is made up of the moulds that contains the feedstock during compression. Figure 5 shows the mould box.

Figure 5 Mould box

3.1.2 Design and Construction of the Pistons

The machine requires an equivalent number of pistons for each of the 32 moulds. The pistons consist of 11 mm long rods and a 10 mm square plate. The pistons were inserted in the openings of each mould and welded upstanding to guarantee simple and free movement in the moulds during operation. The pistons were finally joined together by welding iron rods to the other ends of the rods situated on the 10 mm square plates. (see Figure 6a and 6b).

Figure 6a Pistons

Figure 6b Pistons Set

3.1.3 Design and Construction of the Frame

The frame, holds the mould box, pistons and the hydraulic jack. It wasbuilt with a 20 mm × 20 mm square steel bar and 2 mm angle bar. The casing comprised of four 110 mm long vertical stands which supported the mould box and the pistons. The four vertical bars were welded to the six 11 mm angle bars. Two spaces, both at the top and base were created to permit the insertion and expulsion of the mould boxes after compaction of the biomass material. The frame under construction is shown in Figure 7

Figure 7 Frame

The fully assembled briquetting machine is shown in Figure 8.

Figure 8 Assembled Briquetting Machine

3.2 Hydraulic Jack Selection

The total mass required for the hydraulic jack to overcome in order to produce the compressive force required for the briquete production was determined to be 873.36 kg (see Table 2). Based on this, a one-tonne rated hydraulic jack can be used to provide the required compressive force. However, based on market availability a two-tonne hydraulic jack was used in this study. Table 3.1 also presents other parameters used in the selection of the hydraulic jack.

Table 2 Compaction Force for Briquetting.

Design parameters	Value
Total area at which pressure acts	0.0012 m^2
The total mass of welded pistons	7.5 kg
Mass of 16 wet briquettes	0.72 kg
Mass of mould	12.5 kg
Mass lifted by the Hydraulic Jack	13.22 kg
Weight lifted by the hydraulic jack	129.7 N
Compaction Force for compression of briquettes	8238 N
Total weight lifted by the hydraulic jack.	8367.7 N
Total mass to be overcome by the hydraulic jack	873.36 kg

3.3 Description of the Operation of the Briquette Machine

The two mould boxes are pulled out and filled with the biomass-binder mixture. They are then inserted into the two spaces left in front of the frame to be held firmly by the angle bars.

The first mould box at the top is pushed and adjusted to fit the fixed pistons on top. The second piston is inserted into the second mould box and then pushed onto the second angle bar at the bottom. The hydraulic jack is placed on top of the piston at the bottom. As the hydraulic jack moves, it pushes the mould box at the top to meet the fixed pistons at the top to compress the biomass-binder mixture. As the hydraulic jack extends upward it simultaneously push the pistons below to compresses the biomass-binder mixture in the bottom moulds. Figure 9 shows the briquetting machine in operation.

Figure 9 Briquette Machine in Operation

The biomass loading time, T_1, biomass compaction time, T_2 and the briquette ejection time, T_3 as well as their percentages of the total production time were recorded (see Table 3). The briquette machine, with a production time of 155 produced 32 briquettes at a time compared to that of Amanor (2014) and Nordiana (2010) which produced 25 and 9 briquettes respectively at a time.

Table 3 Production Time of the Briquetting Machine

Stages of Briquette production	Time (s)	Percentage of total production time (%)
Biomass loading time, T_1	40	25.8
Biomass Compaction Time, T_2	60	38.7
Biomass Ejection Time, T_3	55	35.5
Total	155	100

3.4 Results of Briquette Quality Testing

3.4.1 Shatter Index Test

Shatter index measures briquette resistance to mechanical action, which affects its handling and transportation. The shatter index for the briquettes with sawdust to binder ratio of 100: 25 and 100:15 were respectively determined to be 98.6% and 89.3%. The results shows that the stability of the briquettes increases with increase in quantity of binder. Similar findings and trend on the effect of binder content on the shatter index have been reported (Obi, 2015; Tember *et al*., 2014). Higher binder ratio have also been reported to increase the fixed carbon content, volatile matter and calorific value of the briquettes (Ige *et al*., 2020). Borowski (2007) reported that Shatter index should attain a value higher than 90 % in other to ensure that the briquettes is of good quality. This implies that, the developed briquette machine is able to produce briquette of good quality and stability as recommended. Shatter index of sawdust briquettes between 22.1% and 99.16% from sawdust from various wood species have also been reported (Antwi-Boasiako and Acheampong 2016). This indicates that, the findings is within reported values in literature.

3.4.2 Water Resistance Test

The water resistance test determines the response of the briquettes during rainy seasons or while incontact with water. The water resistance capacity for the briquettes with sawdust to binder ratio of 100:25 and 100:15 were determined to be 95.75 % and 88.25 % respectively. Similar findings of 93.75 – 94.24 % have been reported (Pelumi *et al.* (2019). Similar to the shatter index, it can be deduced from the results that increase in the binder content increases the water resistance of the briquettes (Obi, 2015). The finings indicates that, the developed briquettes is able to produced high quality briquettes that can withstand wet conditions.

4 Conclusions

The study on the advancement of a biomass briquetting machine is critical to non-industrial nations as it resolves the issues encompassing the proficient use of plentiful agricultural wastes and residues which give a huge undiscovered fuel asset. The manual biomass briquetting machine developed, produces thirty two biomass briquettes of excellent quality in one production cycle, using a two-ton hydraulic jack. The quality of briquettes produced, depend on feedstock to binder ratio, with 100:25 by mass being the optimal ratio for sawdust briquetting. The optimal briquetting ratio as well as the performance of the machine were obtained based on the shatter index test and water resistance test. At optimal biomass to binder ratio of 100:25 by mass, the shatter index and the water resistance capacity of 98.6% and 95.75 % were resepectively determined. In addition to the ease of usage, the machine also disassembles into four parts, facilitating easy transportation. It is recommened cost benefit anlysis in the production of briquete using the designed machine should be studied.

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