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Development and Evaluation of a Coffee Husk Biomass Briquette Machine

Teka Tesfaye[1*], Adem Tibesso[2] & Abduselam Aliyi[3]

*[1-3]Oromia Agricultural Research Institute, Jimma Agricultural Engineering Research Center, Renewable Energy Engineering Research Team, P.O.Box 386, Jimma, Oromia, Ethiopia. Corresponding Author Email: tekamen@yahoo.com**

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ABSTRACT

Conventional methods for burning coffee husk biomass directly result in high levels of air pollution and very low thermal efficiency. These issues are alleviated, transportation and storage expenses are decreased, and energy production is improved by raising their net calorific values per unit when they are turned into briquettes. Minimizing the impact of coffee by-product constitutes and turning them into an income generation source for the local communities through the development of biomass briquette machines. The experiment used different ratios of carbonized coffee husk and Clay Soil as a binder. The capacity of the machine, Physical and mechanical properties and thermal characteristics of the briquettes were evaluated. Throughput capacity and Degree of Densification of the machine, bulk Density, Resistance to water penetration, Shatter, and Tumbling resistance of the Briquette were increasing with the increase of clay binder ratio with a significant difference at alpha 0.05. The average minimum and maximum throughput capacity and Degree of Densification of the machine were 1.117 and 1.273 kg/min and 290.4 and 308.7%, respectively, at 0 and 25% clay binder ratios. Increasing the clay soil binder ratio increases the percentage of Ash content but decreases the fixed carbon percent and Calorific value. The minimum and maximum Calorific values, Fixed carbon, and Ash content were 3856.89 cal/g, 12.5%, 24%, and 5001.78 cal/g, 30%, and 36%, respectively. Both ignition and water boiling time increase by the increase of clay soil binder ratio with a minimum of 6.5 and 14.3 minutes and a maximum of 7.6 and 18.5 minutes, respectively. It was discovered that clay was the best binding medium for coffee husk, with a clay content of 5% having the best calorific value of 4848.39 Cal/g and the least amount of ash.

Keywords: Briquette; Binder; Carbonized; Coffee husk; Clay soil; Development.

1. Introduction

Desertification is one of the world's biggest problems due to environmental changes and human abuse of forest resources as fuel and building materials (Abakr and Abasaeed, 2006). Most of our nation's urban and rural population, which is rapidly growing, considers forests to be their principal source of fuel. Even though living standards and fashions have changed significantly, particularly in metropolitan areas, traditional cooking practices still predominate. Due to the availability and affordability of wood (most people now collect wood from the neighboring forests for free), it is still the preferred fuel for the majority of local cuisine. This reliance on wood fuel contributes greatly to the nation's declining forest cover and is linked to the unfavorable changes in weather patterns and resulting climate variability that the nation is currently experiencing [2]. Due to the decreased ability for carbon absorption, this overreliance on wood fuel is a major contributor to the loss of biodiversity, declining tree cover, and worsening effects of global warming [3].

Since 30 to 50 percent of the weight of coffee fruit is wasted, the coffee manufacturing business generates enormous amounts of byproducts. Numerous reused solutions have been suggested as a result of the enormous seed production of coffee. Nevertheless, to manage the significant volume of coffee husk, a win-win solution is vital [4].

Coffee husks are regarded as an economically worthless by-product in East Africa, particularly in portions of Ethiopia, and are thrown out in fields and waterways with little use or care. This method of disposing of coffee husks wastes biomass energy and land resources and has a negative impact on the quality of the soil and water. While the planting area expanded from 407,147 ha to 700,475 ha between 2007 and 2016, the yearly production of coffee increased from 273,400 tonnes (t) to 469,091 t. As more processed coffee cherries were produced, the amount of discarded coffee increased. Ethiopia must therefore use coffee husks to increase value, get rid of coffee waste, and lessen environmental damage [5].

Southwest Ethiopia is well-known for its substantial exports of coffee as well as the disposable byproducts of coffee (coffee pulp, husk, and effluents). Nevertheless, these wastes are disposed of in landfills or burned openly, endangering the health of both people and cattle as well as polluting the environment [6]. Due to their low bulk density, coffee husks are more expensive to transport and store [7].

However, only a tiny proportion of biomass residues are utilized as fuel due to their high moisture, polymorphism, and low energy density. These troublesome characteristics increase transport, handling, and storage costs, making using biomass as a fuel impractical. Some of these drawbacks can be overcome if the biomass residues are densified into briquettes to provide more energy per unit volume and uniformity in shape and size [8].

The usual direct burning of biomass is linked to high levels of air pollution and very low thermal efficiency in impoverished nations like Ethiopia. These issues are alleviated, transportation and storage expenses are decreased, and energy production is improved by raising their net calorific values per unit when they are turned into briquettes. The main benefits of briquettes include their high calorific value, simplicity of handling, low sulfur content, and relative dust freedom.

Biomass can be made denser by adding binders that function as glue to hold the particles together. Because simple manual machines may be built to make briquettes and the rate of wear on the devices' parts is decreased, low-pressure densification is preferred. The production of briquettes with appropriate physical qualities requires the complex process of biomass densification, which has a different set of process variables for each biomass feedstock. Coffee husks and clay combinations can make briquettes with the best physical qualities, although the exact quantities of these ingredients are unclear [9].

Rarely was the identification of acceptable binder materials in low-pressure applications studied. During processing at room temperature, binding agents must be provided from outside. There are numerous materials that can be used to create these binders. The most economically feasible solutions for this application are waste or readily accessible resources.

The three individual machines in the existing briquette system work together, including a hammer mill for grinding the carbonized; the fined charcoal and binder are thoroughly mixed at a predetermined mixing ratio and then transferred to a briquette machine to be extruded into briquettes. The briquettes are then cut and dried before being delivered to the store. The proposed design for a new briquetting system (a compact machine and one worker): carbonized material is transferred to a compact device, and the binder is added to the mixing container in which both grinding and briquette making take place. Briquettes are ejected from the die.

As a result, the study was conducted to determine the levels of process variables under which to produce coffee husk briquettes of optimum quality at the lowest pressure possible. So, with clay soil as a binder, it aimed to minimize the environmental hazards that coffee waste constitutes in the coffee processing industry and turn them into income-generating sources for the local communities.

2. Aim and Objectives

Aim

The aim of the study was to develop and evaluate the performance of the briquette machine using coffee husk biomass.

Objectives

The purpose of this study was to determine the efficiency and capacity of the briquette machine performance using different ratios of carbonized coffee husk and clay soil as a binder.

3. Materials and Methods

3.1. Description of the study area

The study was carried out at the Jimma Agricultural Engineering Research Center in the Oromia region of Ethiopia, 353 kilometres southwest of Addis Abeba. The zone spans a total area of, 18415 km2 and is situated between latitudes 7°18′ and 8°56′N and longitudes 35°52′ and 37°37′E. Nitisol and comb soils are the predominant soil types in the region, and 1,467 mm of rain falls on them annually on average [10].

The annual average temperature is 20 °C. The agro-ecological conditions in the research area range in altitude from 1100 to 1400 masl for lowlands, 1400-1700 masl for intermediate terrain, and 1700–2200 masl for highlands [11].

3.2. Materials and Instruments used

Materials that are required for the manufacturing of the briquette machine were identified and selected based on the design specification. According to this, Sheet metals, Square pipes, Circular hollow pipes, a Bearing, a Screw shaft diameter of 35 mm, an Engine pulley diameter of 14 cm and Screw pulley diameter of 46 cm, an Engine motor of 10 hp, a Stopwatch, Oven dry, Thermometer, and Digital Balance were used.

3.3. Design calculations

3.3.1. Design of Extruder (the screw)

Diameter and pitch of last flight of compression zone

The volume of the last flight of the feeding zone, $V_f = \frac{\pi}{4}({D_1}^2 - {D_3}^2)*\text{pitch}$ (3.1)

To calculate the pitch of the compression zone, assume the diameter of the last flight of the compression zone

$$V_c = \frac{\pi}{4}({D_1}^2 - {D_3}^2)* P_c \tag{3.2}$$

3.3.2. Motor power required

Helix angle (α) of acme thread calculated as:

$$\tan\alpha = \frac{\text{pitch}}{\pi D} \tag{3.3}$$

μ_1 = Virtual coefficient of friction

β = Angle of acme thread

$\mu_1 = \tan\varphi_1 = \frac{\mu}{\cos\beta}$

The force required overcoming friction at the screw,

$$F = W\tan(\alpha+\varphi_1) \quad (3.4)$$

W = Axial load exerted by the screw

$$F = W\left[\frac{\tan\alpha + \tan\varphi_1}{1-\tan\alpha * \tan\varphi_1}\right] \quad (3.5)$$

Mean diameter of last flight of compression zone

$$d = D_2 - \frac{p_c}{2} \quad (3.6)$$

The torque required overcoming friction at the screw

$$T = F*\frac{d}{2} \quad (3.7)$$

The power required to drive the screw is

$$P = T*\omega \quad (3.8)$$

3.3.3. Determination of the shaft speed

The transmission system is belt transmission via a pulley (specifically v belt selection) using a mechanical drive petrol engine or an electrical motor. Thus to calculate the shaft speed, the following parameters are used:

$$\frac{D_1}{D_2} = \frac{N_2}{N_1} \quad (3.9)$$

$$N_2 = \frac{D_1}{D_2}*N_1$$

Where

N_1= Revolution of the smaller pulley, rpm.

N_2 = Revolution of the larger pulley, rpm.

3.3.4 Determination of the belt contact angle

The belt contact angle is given by

$$\sin\beta = \frac{(R-r)}{c} \quad (3.10)$$

Where

R = radius of the large pulley, mm

r = radius of the smaller pulley, mm

The angles of wrap for the pulleys are given by

$$\alpha_1 = 180 - 2\sin^{-1}\left(\frac{R-r}{c}\right) \quad (3.11)$$

α_2 = 180 +2$\sin^{-1}(\frac{R-r}{c})$ (3.12)

Where

α_1 = Wrapping angle for the smaller pulley, degree

α_2 = Wrapping angle for the smaller pulley, degree

3.3.5. Determination of the belt tension

Tangential load:

The belt tension was calculated using a Textbook by 'Khurrmi and Gupta formulas.

Maximum tension in a belt:

$T = SA$ (3.13)

Centrifugal tension in the belt

$T_c = mv^2$ (3.14)

$T_1 = T - T_c$

To get tension in the slack side, use the relationship below

$2.3 \log (\frac{T_1}{T_1}) = (\frac{\mu\alpha_1}{\sin\theta})$ (3.15)

Where

T_1 = Tension in the tight side, N

T_2 = Tension in the slack side, N

θ= Angle of groove ranges

μ = coefficient of friction between the belt and the pulley

S = The maximum permissible belt stress, MN/m

The power required by the shaft is given by

$P = (T_1 - T_2)*V$ (3.16)

The torque at the main shaft is given by

$T = (T_1 - T_2)*V$ (3.17)

3.3.6. Design of mixing system

The volume of the cylinder:

$V = \pi r^2 L$ (3.18)

Where:

V [mm^3], r = radius in [mm], L = length in [mm]

The volume of material, V_m [mm^3]:

$V_m = 0.2*V$

Mass of mixing trough, M [Kg]:

$$M = V_m*\rho \tag{3.19}$$

Where ρ [Kg/m^3] is the density of the design material.

3.3.7. Design of Shaft and Blade

Normal load acting horizontally:

$$W_{tx} = \frac{2T_x}{D_x},\ W_{ty} = \frac{2T_y}{D_y},\ W_{tz} = \frac{2T_z}{D_z} \tag{3.20}$$

Where T_i [Nm] is the torque on the blade and the subscript 'i' represents blades x, y, and z.

The normal load exerted:

$$W_{nx} = \frac{W_{tx}}{\cos\theta},\ W_{ny} = \frac{W_{ty}}{\cos\theta},\ W_{nz} = \frac{z}{\cos\theta} \tag{3.21}$$

Normal load acting vertically:

$$W_{nvx} = W_{nx}\cos\theta,\ W_{nvy} = W_{ny}\cos\theta,\ W_{nvz} = W_{nz}\cos\theta \tag{3.22}$$

$$W_{nhx} = W_{nx}\sin\theta,\ W_{nhy} = W_{ny}\sin\theta,\ W_{nhz} = W_{nz}\sin\theta \tag{3.23}$$

3.4. Machine description and Experimental procedure

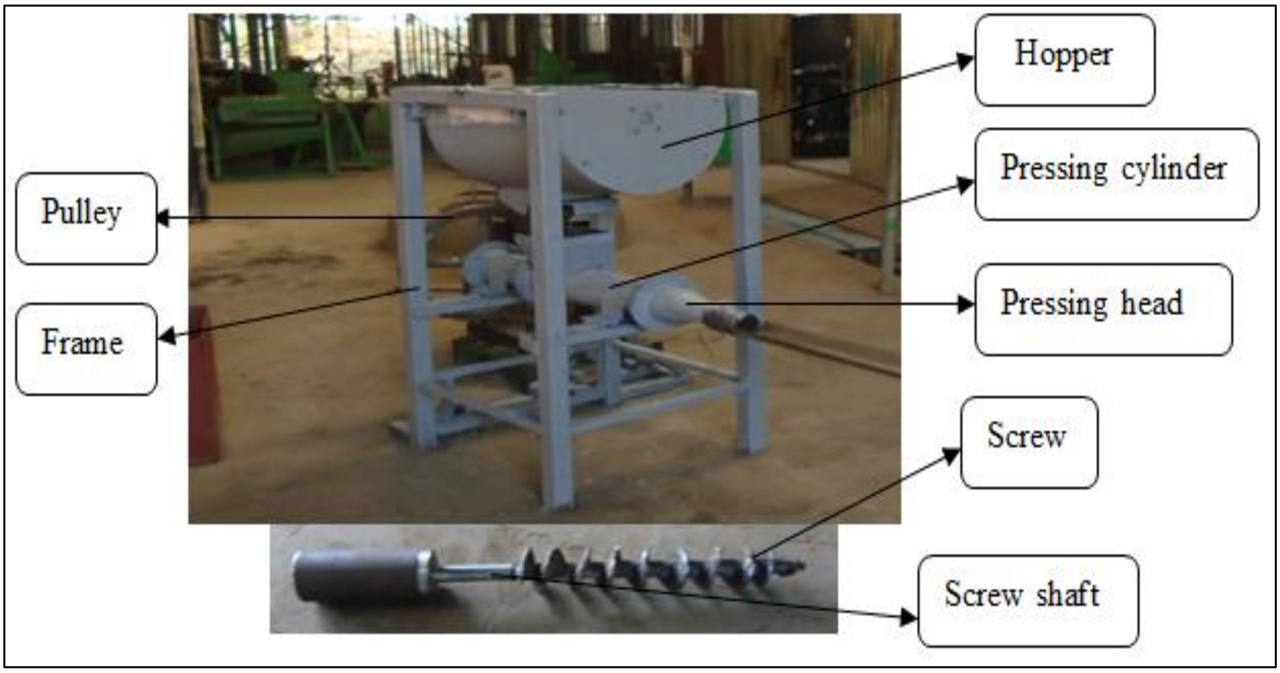

Figure 1. The detailed components of the developed briquette machine

Table 1. Components specification of the briquette machine

Parts	Description
Overall size of machine	126 cm×72 cm
Size of frame	60 cm×72 cm
Hopper	Concave 1.5 mm sheet metal
Pulley	$D_o = 46$ cm
Frame	4×4 square pipe 2 mm thickness
Pressing head	$D_i = 5$mm pipe
Pressing cylinder	$D_i = 12$ cm
Screw	6 cm pith diameter
Screw shaft	D = 35mm

Carbonized coffee husk and Clay Soil as a binder was used with a ratio of 100%, 95%, 90%, 85%, 80%, and 75% carbonized coffee husk and 0%, 5%, 10%, 15%, 20% and 25% clay soil respectively. Half of the weight of the ingredients (Carbonized coffee husk and Clay soil binder) water in a litre was added and mixed in the mixing chamber. Both Crushing and Extruding were done at the same time and within the extruding chamber. The experiment was done by adjusting the engine motor Speed to 1700 rpm using the fuel valve, causing the speed of the screw pulley to 518 rpm. The samples were weighed using a Model CTI200-s scale with capacities of 6, 1.2 kg and precisions of 1, 0.1 g, respectively. The moisture level is measured in this study using the drying oven method.

3.5. Performance evaluation parameters of the machine

3.5.1. Throughput capacity of the machine (C_t)

The biomass briquette machine's throughput capacity was calculated as the mass of briquettes produced divided by the average production time [12].

$$C_t = \frac{m_b}{t_b} \qquad (3.24)$$

Where: Ct is the throughput capacity (kg/s), m_b is the mass of Briquette produced at time t (kg), and t_b is the briquette production time (s).

3.5.2. Physical and mechanical properties of briquettes

Bulk density: The bulk density of the produced fuel briquettes was determined by measuring the volume and weight of samples. The weighing was performed using the analytical balance, and the dimensions were measured using a Vernier calliper. The density was calculated by determining the material's ratio of mass and volume [13].

$$\text{Bulk density (kg/m}^3\text{)} = \frac{\text{mass of biomass sample (kg)}}{\text{the volume of the measuring cylinder (m}^3\text{)}} \qquad (3.25)$$

Shatter resistance test:

This test was conducted to determine the hardness of the Briquette. The known weight and length briquette were dropped one meter on a concrete floor ten times. The percent loss of materials was calculated. The Briquette's shatter resistance was calculated using the following formula [14].

Percent weight loss = $\frac{w_1-w_2}{w_1} * 100$ (3.26)

% shatter resistance = 100 % weight loss

Where W_1 = weight of Briquette before shattering, g

W_2 = weight of Briquette after shattering, g

Tumbling resistance test

The abrasion resistance test, commonly referred to as the tumbling test, evaluated the mechanical toughness of products that had undergone densification due to handling and transportation procedures. The Briquette experienced controlled shocks as a result of fuel particles slamming onto rotating chamber walls and each other. According to EN 15210-2, the tumble procedure was carried out for 5 minutes in a clockwise direction at a speed rate of 25 rpm. To get rid of the particulates that were adhered to the sample, sieving was necessary both before and after the 30 seconds of tossing [15]. The Briquette's weight loss was then noted, and tumbling resistance was computed using the formula below.

Percent weight loss = $\frac{w_1-w_2}{w_1} * 100$

%Tumbling resistance = 100 % weight loss

Where W_1 = weight of Briquette before tumbling, g

W_2 = weight of Briquette after tumbling, g

Resistance to water penetration:

It shows how the briquettes respond during rainy seasons or while in contact with water [16]. The percent of water gained was noted, and the following formula calculated water penetration resistance.

Water gained by Briquette = $\frac{w_1-w_2}{w_1}*100$

% Resistance of water penetration = 100 % water gained

Where, W_1 = initial weight of briquette, g

W_2 = final weight of briquette, g

Degree of densification:-

The degree of densification is defined as the percent of the increase in density of biomass due to briquetting. The degree of densification represents the ability of materials to be bounded. It was calculated and recorded by using the equation below [17]:

$$\text{Degree of densification} = \frac{\text{the density of briquette} - \text{density of raw materials}}{\text{the density of raw materials}} \qquad (3.27)$$

3.5.3. Thermal characteristics of the briquettes

Proximate analysis

Analysis for moisture, volatile matter, ash, and fixed carbon contents was carried out on samples of Briquette at the Ethiopian Rural Energy Development and Promotion Center, Alternate Energy Technologies Design, prototype, and Testing Directorate Energy Efficiency Laboratory Unit. The calorific values of the samples were measured in a Bomb calorimeter apparatus [18].

Ignition and water boiling time:

To boil 2.5 L of water in an aluminum pot, 500 grams of briquettes were weighed out and placed on a metal household briquette stove. Time taken for the briquette sample to start burning uniformly and the time for boiling the water was recorded in minutes.

4. Results and Discussion

4.1. Throughput capacity and degree of densification of the machine

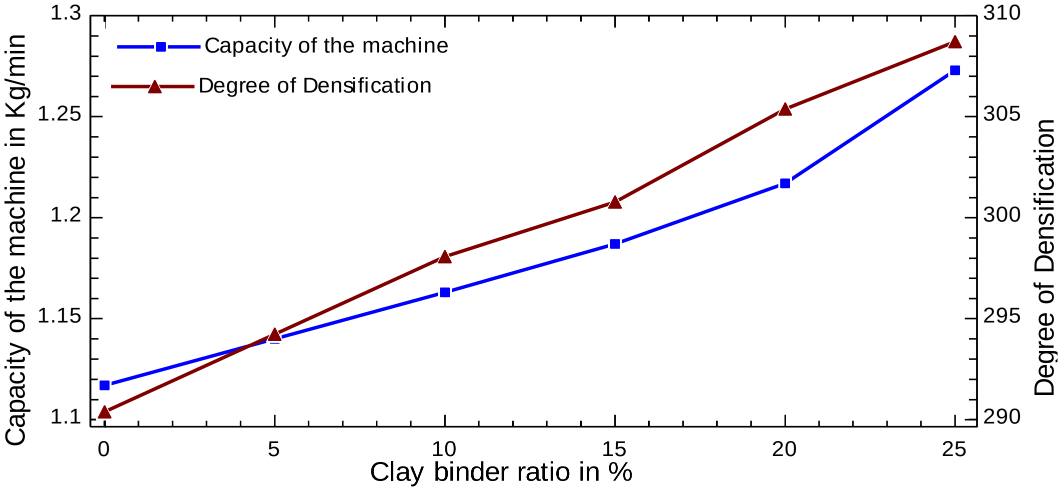

Figure 2. The result of throughput capacity and degree of densification of the machine

From figure 2, the machine's average throughput capacity and Degree of Densification increased with the clay binder ratio. The average minimum and maximum throughput capacity and Degree of Densification of the machine were 1.117 and 1.273 kg/min and 290.4 and 308.7%, respectively, at 0 and 25% clay binder ratios. The machine capacity of this study was similar at a 5% clay binder ratio compared to the study of [19], in which the machine capacities were 68.56 kg/h. But compared with the study [12], the capacity of 0.0055 kg/s, the result was much different, and this may be due to the power source being a 2.0 hp electric motor versus a 10.0 hp Acme engine. The result of the study [20]; the degree of densification of powdered vegetable market waste briquette was found to be 231, 203, 202 and 219 % for cauliflower + cabbage leaves, coriander stalk + leaves, field beans, and green pea pods, respectively. The difference may be due to its physical nature, which gave higher quality compaction of carbonized coffee husk.

4.2. Bulk density of briquettes and resistance to water penetration

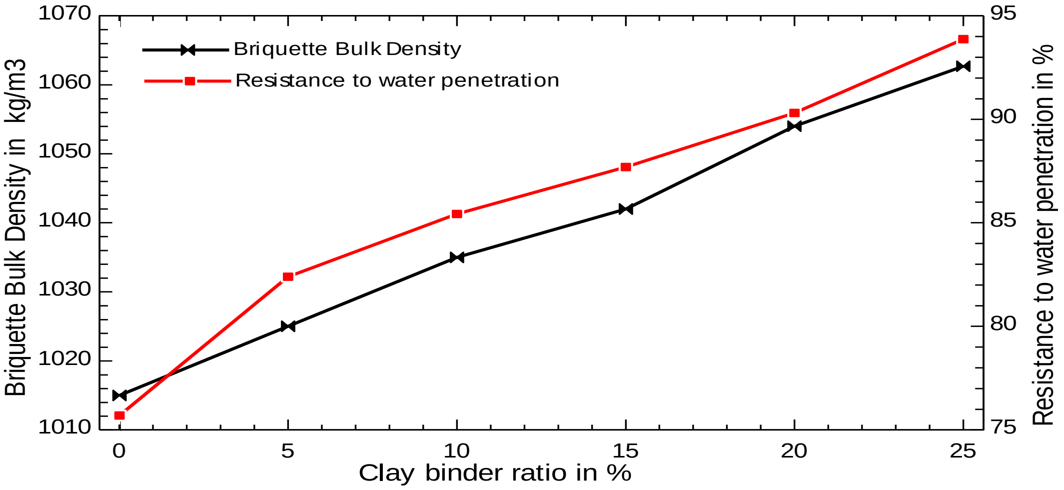

Figure 3. The result of bulk density and resistance to water penetration

As indicated in Figure 3, the bulk density and resistance to water penetration increase as the ratio of binder increases. The highest bulk density and resistance to water penetration were 1062.667 kg/m^3 and 93.867%, respectively. According to the study [21], the bulk density of briquettes and pellets manufactured using coffee pulp was 1110 and 1300 kg/m^3. In the study [22] on the Briquette of coffee husk at different particle sizes, the maximum bulk density at 25% clay soil binder ratio was 769.2 kg/m^3. The quantity and type of binder were discovered to be the most important factors influencing briquette density, followed by particle size. The combustibility of the same binding agent increases with increasing briquette density. Investigation results on the performance of sawdust briquette blending with neem powder resistance to water penetration ranged from 73 to 90% [16]. In this study, all the categories of briquettes fall within the acceptable quality value (>70%) based on the [23] study.

4.3. Shatter and Tumbling resistance test

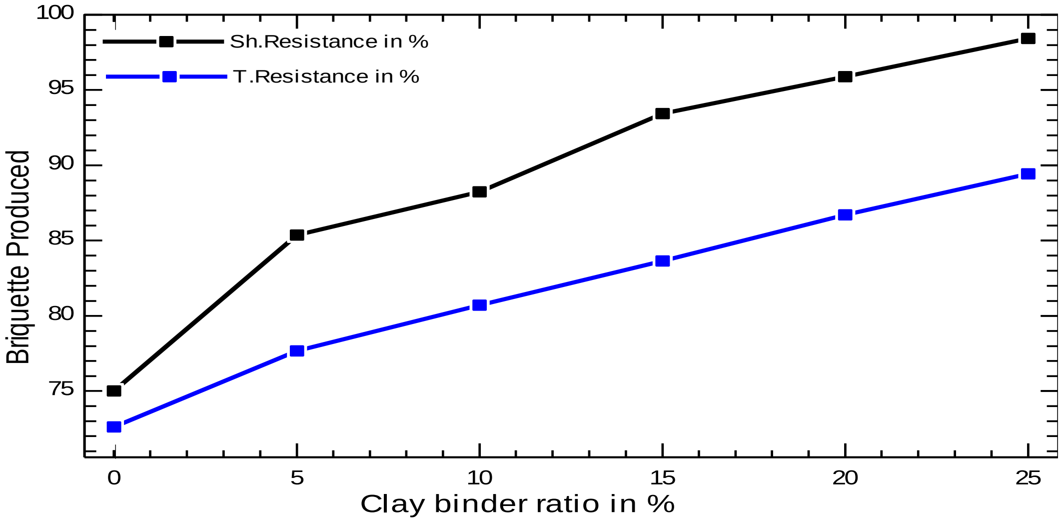

Figure 4. Shatter and Tumbling resistance

From figure 4, it was observed that both Shatter and Tumbling resistance increased with an increase in binder ratio. According to [15], a high-quality briquette must have a minimum of 90% shatter resistance in order to meet the requirements. Using this as a guide, it can be determined that the briquettes produced at the various binding ratios exhibited shatter resistance ranging from about 75% to 98.4%. The 15 to 25% clay soil binder ratio fell within the acceptance limit range. Thus they were considered quality briquettes. A tumbler test was carried out to check the durability index of the briquette fuel. The maximum (99.35%) and minimum (93.31%) tumbling resistance were observed in the study [17]. The difference may be due to the type of biomass and binder used.

Table 2. The LSD test for treatments to see the effect of binder ratio at alpha: 0.05.

Treatments	Capacity kg/min	Bulk density kg/m3	Shatter Resistance in %	Tumbling Resistance in %	R.t. Water Penetration in %	Degree of Densification
Clay 25%	1.27^{a}	1062.67^{a}	98.43^{a}	89.43^{a}	93.87^{a}	3.087^{a}
Clay 20%	1.22^{b}	1054.0^{b}	95.88^{b}	86.70^{b}	90.3^{b}	3.05^{b}
Clay 15%	1.19^{c}	1042.0^{c}	93.43^{c}	83.63^{c}	87.7^{c}	3.01^{c}
Clay 10%	1.16^{cd}	1035.0^{d}	88.23^{d}	80.69^{d}	85.4^{d}	2.98^{d}
Clay 5%	1.14^{de}	1025.0^{e}	85.37^{e}	77.66^{e}	82.4^{e}	2.94^{e}
Clay 0%	1.12^{e}	1015.0^{f}	75.00^{f}	72.61^{f}	75.7^{f}	2.90^{f}
CV %	1.41	0.31	0.59	1.23	1.28	0.42

*Treatments with the same letter do not differ significantly

4.4. Proximate Analysis

As shown in the figure, increasing the clay soil binder ratio increases the percentage of Ash content but decreases the fixed carbon percent and Calorific value. Generally, high carbon content influences combustion behaviour, affecting ash fusion.

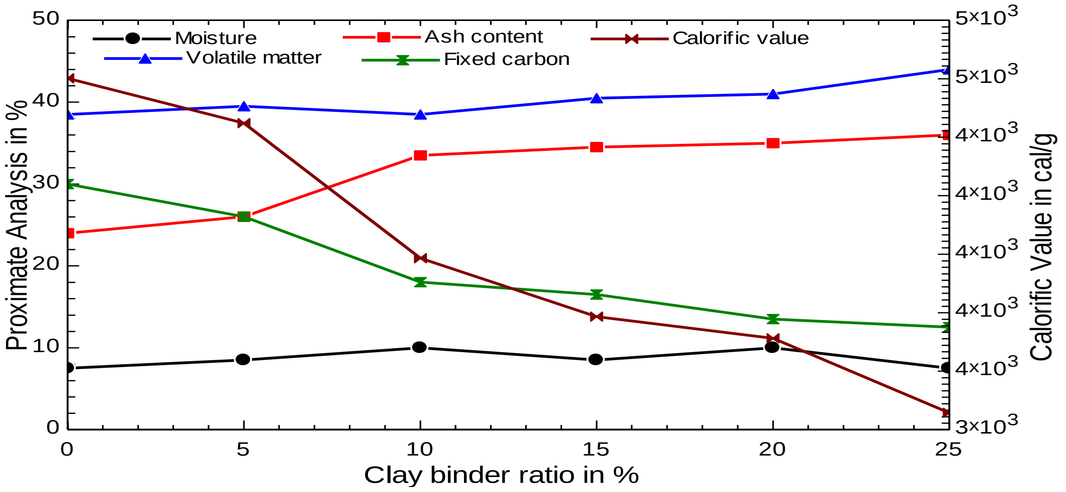

Figure 5. The proximate analysis results of the coffee husk briquette

Under the proximate analysis study, ash is the primary inorganic substance obtained after biomass combustion; ash typically contains calcium, potassium, magnesium, and phosphorus. Mineral deposition and agglomeration in ash melt is one issue that prevents the thermal process of biomass [24]. As a result, a higher fixed carbon content encourages more calorific energy in the charcoal produced. A higher fixed carbon content translates into a lower volatile matter content. As the briquette enters the volatile combustion phase, its overall mass decreases. Increasing the hydrogen-to-carbon ratio augmented the combustion, although to a lesser extent, as the carbon ratio rises [25]. The moisture content values (7.5 to 10%) comply with the range established for this categories of product, i.e., 10 to 12%, according to the DIN 51731 standard (Deutsches Institute fur norming, 1996). An adequate moisture content level in briquettes allows sufficient heat and temperature in the chamber and reduces the amount of exhaust gas [26]. According to the study [27], Briquette produced from bagasse clay as a binder in the ratio of 20:80 and molasses as a binder in the ratio of 10:90 were greater than the fixed carbon content of the charcoal briquette produced from sawdust briquette which was a fixed carbon content of 20.7%. Fixed carbon is the major quality measuring parameter that determines the energy behaviours in the production of densified biomass briquettes.

In the study [28], the physical attributes, including volatile matter, ash content, and fixed carbon, were in the range of 27 to 37%, 14 to 33%, and 31 to 39%, respectively, for waste from rain trees (Samanea Saman) and coffee ground/tea waste. High levels of volatile matter facilitate ignition and improve combustion. A high ash concentration, on the other hand, reduces the heating value. According to the study's report [29] on the potential of coffee husk and pulp as a sustainable alternative energy source, it enhances the thermal barrier to heat transfer. According to the findings of the study [30], the amount of clay binder rose from 15% to 25%, but the calorific value dropped from 4647 Cal/g to 3389 Cal/g. Additionally, the ash content goes from 25% to 40%. As a result, sesame stalk charcoal has an ideal calorific value of 4647 Cal/g with minimal ash concentration. The amount of ash left over after burning is one factor that affects the quality of biomass charcoal. Due to the clay's approximately 90.1% ash composition, the ash content rises as the percentage of clay does. Due to the low carbon content of clay, which is only 7.1%, the percentage of fixed carbon in sesame stalk briquettes has fallen from 44.4% to 29.63% when the proportion of clay increases from 15% to 25% [31].

The optimal clay content is 5%, with an optimal calorific value of 4848.39 Cal/gm and minimum ash content, as shown in figure 5, where the rate of increment of ash content and rate of decrement of calorific value and fixed carbon content are high as the percentage of clay increases from 5% to 10%.

4.5. Ignition and water boiling time

As shown in the figure, both ignition and water boiling time increase by increasing the clay soil binder ratio with a minimum of 6.5 and 14.3 minutes and a maximum of 7.6 and 18.5 minutes, respectively. With increasing binder concentration and compaction pressure, the ignition time lengthened. Increased compaction pressure automatically increased briquette density, which led to a delay in the briquettes' igniting period. This can be explained by the fact that the briquette's bigger pores allowed for more air to sustain combustion. However, the values obtained from the various studies were within the range of 19-186 s for bio-coal briquettes formed by mixing the ingredients at varying percentages of 10-50% with coal. In the study [32], the ignition time was between 109 s and 140 s. In comparison to firewood, which took 21 minutes to boil the same amount of water, rice husk-starch briquettes heated water in 15 minutes? The briquettes with higher calorific values had the fastest burning rate, which resulted in the fastest water boiling time. Compared to briquettes with low heating values, they were able to boil water more quickly.

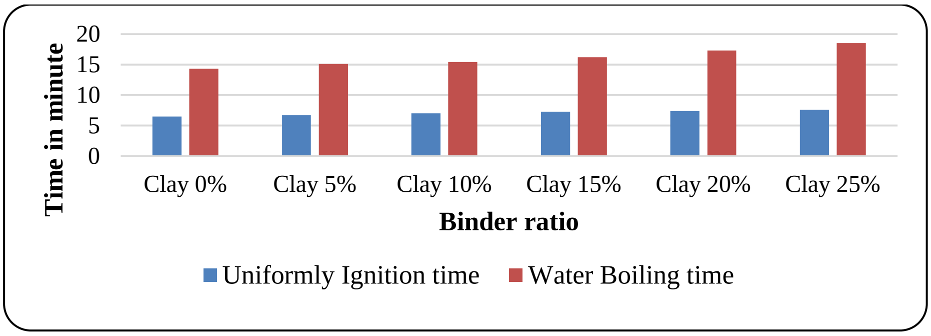

Figure 6. The effects of binder ratio on the ignition and water boiling time

Figure 7. The final produced Briquette

When compared to the results of the biomass used in this study, the results from other biomass briquettes (T.K., S and A. O. Y., 2016) revealed the quickest water boiling time, with coal briquettes taking 26 minutes, cassava starch gel taking 18.05 minutes, and orange waste taking 15.00 minutes. It may be said that the briquettes made are suitable for cooking in a home setting.

5. Conclusions and Recommendations

The research reveals the potential to produce more than 67.02 kg charcoal per hour. The study has found that the binder ratio significantly affected the physical and combustion characteristics of briquettes produced from the carbonized coffee husk. The briquettes produced have sufficient density and degree of densification. The bulk density of the briquettes was 1015 to 1062.667 kg/m^{3,} which is higher than the residue materials, which is 150.73 kg/m^3. These translated into a 673.4 to 705.01% volume reduction. Therefore, high-quality and storable briquettes can be produced from the blend based on the results obtained. It is because the relaxed density and compressive strength of the briquettes produced are adequate; besides, the stored briquettes' length of time or service life proved satisfactory and acceptable stability even after some months of storage.

The combustibility test also revealed that biomass densification, as opposed to bulk biomass, promotes greater energy performance. It was discovered that clay was the best binding medium for coffee husk, with a clay content of 5% having the best calorific value of 4848.39 Cal/g and the least amount of ash. Additionally, by substituting renewable, clean, and sustainable energy for fuel wood and charcoal, the creation of briquettes from coffee husk lowers the rate of deforestation, which increases the mechanism of carbon sequestration. The briquette makers and the carbonizer are produced locally in the research center workshop, making it simple to make them available in the area's small and medium metal fabrication shops. This will have a positive impact on the technology transfer and innovation that young people and women can do to improve their quality of life. Therefore, if careful consideration is paid to the technologies, they can be demonstrated. Using an electric motor instead of a fuel engine motor for sustainability and capacity improvement as a source of power where electric power is available.

Declarations

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Competing Interests Statement

The authors declare no potential conflict of interest.

Consent for publication

The authors declare that they consented to the publication of this research work.

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