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Production and Characterisation of Coffee Husk Briquette

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Abstract- The study investigates the production and characterization of coffee husk briquettes using cassava starch as a natural binder to develop an efficient, renewable, and eco-friendly alternative to conventional fuels. Coffee husk, an abundant agro-waste from coffee processing, was combined with cassava starch in varying ratios (0%, 10%, and 20%) to enhance fuel quality and mechanical properties. The briquettes were produced using a hydraulic densification process and evaluated for mechanical strength, proximate composition, and combustion performance in accordance with ASTM standards. Results revealed that increasing the binder content improved the briquette's relaxed density, shatter resistance, and water resistance, with the highest density (671.2 kg/m³) recorded at a binder content of 20%. Proximate analysis revealed a decrease in moisture and volatile matter, accompanied by an increase in fixed carbon and calorific value, as the binder ratio increased. The optimal calorific value of 29.08 MJ/kg obtained at 20% binder closely compares with that of conventional charcoal (31.38 MJ/kg), confirming the high energy potential of coffee husk briquettes. Furthermore, combustion tests showed that higher binder ratios prolonged ignition time but enhanced burning stability and reduced ash formation. The study concludes that coffee husk briquettes bound with cassava starch exhibit desirable physical and combustion characteristics, making them suitable for both domestic and small-scale industrial applications. Adopting this technology could mitigate deforestation, reduce dependence on fossil fuels, and promote sustainable waste-to-energy conversion, especially in coffee-producing regions. Thus, coffee husk briquetting presents a practical pathway toward renewable energy utilization and environmental sustainability.

Keywords: Coffee husk briquette; Cassava starch binder; Renewable fuel; Calorific value; Sustainable energy; Agro-waste utilization; Environmental sustainability

I. INTRODUCTION

Global efforts have been made to identify sustainable and renewable energy sources that are more environmentally friendly and can replace non-renewable energy sources, such as fossil fuels. (Matias J. et al, 2011). There is growing awareness about the ecological consequences of fossil fuel consumption and considerable government subsidies in most nations worldwide to increase renewable energy penetration (United Nations, 2015).

Biomass, a promising renewable energy source that serves as an alternative to wood fuel in Nigeria, presents a significant opportunity as a feedstock for bioenergy due to its substantial availability as a waste product. (Ofori and Akoto. 2020; Phonphuak and Thiansem, 2012).

Biomass wastes such as sawdust, agricultural, food, and paper waste are produced in substantial amounts in Nigeria. Still, their use as an alternative fuel for homes and industrial applications is inefficient. This is due to their inherent burning characteristics, which include high moisture content, low heat emission, and smoky discharge. The type of biomass required for biomass briquetting is primarily determined by the energy conversion process and the form in which the energy is needed (Abubakar et al, 2020).

A bulk of coffee husk and pulp, which are generated as waste from coffee berry processing, can be used as a feedstock for biomass briquettes to minimise the over-reliance on wood resources and fossil fuels. Based on a 0.2 waste factor for coffee, reported by Abbasi et al (2010), out of every metric tonne of Coffee berry produced, 0.2 metric tonne is available for biomass energy production.

The utilisation of coffee as organic manure for acidic crops and biomass fuel is still limited, rendering it an economically worthless by-product in the growing communities in Nigeria.

To utilise coffee husk as a sustainable biomass fuel, such as a briquette, the inherent problems of high moisture content, irregular particle size and shape, and low density must be addressed to facilitate ease of handling, transportation, storage, and utilisation. Briquettes help reduce deforestation by complementing firewood and charcoal for domestic cooking (Ajit, 2017).

Since coffee husks still have the potential to be combusted for energy used in household cooking and industrial applications, utilizing coffee husks to produce briquettes as an alternative fuel should be considered.

Therefore, the objectives of this study were to produce fuel briquettes of optimum quality from coffee husk using the hydraulic densification method and to evaluate the effect of cassava starch binder ratio on the energy potential and fuel properties of coffee husk briquettes as an alternative source of fuel to reduce the pressure on wood fuels.

The present study produces the briquettes by mixing cassava-based starch with coffee ground coffee husk in a 0-20% mixing ratio. Measurements of mechanical, physicochemical, fuel, and combustion properties are compared with those of charcoal briquettes to evaluate the potential of Coffee husk briquettes as an alternative fuel and determine the optimal manufacturing conditions.

This aims to reduce the degradation of natural forests by lowering pressure on wood fuels, minimizing the environmental hazards that coffee waste poses in coffee processing communities, and turning them into income-generating sources for local communities.

II. MATERIALS AND METHODS

2.1 Preparation of coffee husk and binder

About 5 kg of freshly depulped Coffee husk was obtained from the crop processing unit of the Value Addition Department of the Cocoa Research Institute of Nigeria (CRIN), Ibadan, Oluyole Local Government, Oyo State, Nigeria. The biomass was sorted to remove impurities mixed with it, such as stones and dirt. It was sun-dried to reduce the moisture content to approximately 10%, as suggested by Pandy and Dhakel (2013). The dried Coffee husk was ground using an electric grinder and passed through a 10-mesh screen to obtain sample particles of 1.4 mm, used for briquettes. The binder used was a cassava-based starch obtained from Odo-Ona Market, Oluloye local government, Oyo State, and was prepared by mixing 30g of the starch with 15 cm^3 of water at an ambient temperature of 27℃ and then 70cm^3 of boiling water, which was stirred gently with boiling water at 100℃ to form a smooth, homogeneous, gelatinized starch paste.

2.2 Coffee Husk Briquetting Process.

Coffee husk, divided into three equal parts, was mixed with starch paste in the ratios 100:00, 80:10, and 80:20. Coffee husk briquettes with the same particle size of 1.5 mm. 200g each of the mixture of Coffee with and without binder was fed into a manual cylindrical briquette fabricating mould of diameter 50mm and height 70mm. Three replicates of the coffee husk briquette produced with or without a binder were stored at room temperature for 14 days to dry (Sarafa et al., 2020; Imeh, 2017). The briquettes were produced at the Forestry Research Institute of Nigeria, Jericho, Ibadan, Nigeria.

2.3 Characterisation of Briquette

The produced briquettes and figures were laid out flat in a sealed space with sufficient air ventilation, and air-dry was allowed for 21 days to attain a stable moisture content of 9.5% before the properties were characterised. Three samples of coffee husk briquettes were analysed to determine their fuel and combustion properties. The mechanical properties, proximate analysis, and combustion properties were determined using standard methods. The wood charcoal product was used as a standard for comparing all the parameters analysed. To study the effects of coffee husk–cassava starch mix on the fuel and combustion properties of the briquette, three different mix levels, CH0, CH1, and CH2, which correspond to 100:00, 90:20, and 80:20 coffee husk briquettes with the same particle size of 1.5 mm, were used for the characterisation of the briquette. The varying coffee husk–cassava starch mix was investigated to determine its effect on the strength, fuel, and combustion characteristics of coffee husk briquettes.

2.5 Mechanical properties

2.5.1 Relaxed Density

The density of the briquettes was determined according to the American Society of Agricultural and Biological Engineers (ASABE S269.4) standard methods. The volume was measured using the Venire callipers to measure the height and diameter of each briquette. The average measurement was taken in each case (Nino et al., 2020). The mass of the briquette produced was measured using a laboratory weighing balance with a correctness of 0.01 g. The density of the briquettes was then calculated using Equation 1.

$$\rho = \frac{M_1}{V} \times 100 \qquad (1)$$

Where,

ρ = density of the briquette (kg/m^3)

M = the mass of the briquette (g)

V = the volume of the briquette (cm^3)

2.4.2 Shatter Index

The Shatter index measures the briquette's hardness. The durability of the briquette was measured during transportation to determine its safe height during production. In the present study, a briquette with a known length and mass was released to fall from a height of approximately 1 m onto a reinforced concrete floor (RCC) 10 times. The fraction of the briquette retained was used as an index of briquette breakability. The remaining portion was reweighed, and the shatter resistance of the briquettes was determined according to Equation 2, as suggested by ASTM International (2007).

$$SH = 100 - (M_2 - M_3)\frac{100}{M_2} \qquad (2)$$

Where: M_8 = mass of briquette before shattering (g)

M_9= mass of briquette after shattering (g)

and SH is the shatter resistance (%)

2.4.3 Water Resistance

The water absorption of a briquette depends on the porosity of its composition. The water resistance of pre-weighted samples of dried briquettes was tested by immersing them in water at room temperature for two minutes. The difference in weights of the dried and wet briquette samples, expressed as a percentage of the dried sample weight, provided a measure of the briquette's water resistance. The water resistance was calculated using Equation 3, as suggested by Tayade (2009).

$$WR = (M_4 - M_5)\frac{100}{M_{10}} \qquad (3)$$

Where = Water resistance, %

M_4 = Mass of briquette sample after immersion, g

M_5 = Mass of briquette sample before immersion, g

2.5 Proximate Analysis

2.5.1 Moisture Content

The moisture ratio of the dry weight of the coffee husk briquette was determined by drying 5 g of the briquette sample, placed in a crucible of known mass, in an oven at 105˚C for 24 hours. The mass of the crucible was measured and recorded. The sample in the crucibles was cooled and then measured after drying. This procedure was repeated to obtain a constant weight, and the moisture content of the coffee husk briquettes was determined using the ASTM D-3173 2017 standard, according to equation 4

$$M.C = (M_6 - M_7)\frac{100}{M_7} \qquad (4)$$

Where $M.C$ = moisture content of the coffee husk briquette

M_6 = mass of briquette before drying (g)

M_7 = mass of briquette after drying (g),

2.5.2 Ash Content

Ash is a constituent obtained when solid fuels are heated to a constant

Mass. 5 grams of the grounded sample were measured into a porcelain crucible. The sample with the crucible was put into a furnace for four hours at 550˚C. The furnace was allowed to cool below 200 °C for 20 minutes. The crucible containing ash was removed from the stove and placed in a desiccator to cool. The mass of the ash in the crucible was measured to determine the ash content of coffee husk briquettes, as per the ASTM D-3174-2012 standard. This is expressed by equation 5

$$A.C = (M_8 - M_9)\frac{100}{M_8} \quad (5)$$

Where $A.C$The Ash Content of the briquette (%)

M_8 = the initial mass (g) of the ground briquette

M_9 = the mass (g) of the sample heated for four hours at 550˚C

2.5.3 Volatile Matter

The combustibility of a given sample of bio-briquette is a function of its volatile content. The briquette test sample was heated at 900˚C for 7 min, and the percentage of volatile content was calculated based on the measured mass loss of the sample on cooling in a desiccator. The amount of volatile matter was calculated using the ASTM D-3175 2018 standard according to Equation 6

$$V.M = (M_{10} - M_{11})\frac{100}{M_{10}} \quad (6)$$

Where $V.M$ is volatile matter of the briquette (%)

M_{10} = the mass (g) of the sample before heating.

M_{11} = the mass (g) of the sample after heating at 900˚C for 7 min.

2.5.4 Fixed Carbon

Fixed carbon content of the sample was calculated by adding the percentage moisture content, percentage ash content, and percentage volatile matter and deducting from 100%, according to ASTM D-3712-13, using equation 7

$$F.C = (100 - \mathrm{M.C} - \mathrm{V.M} - \mathrm{A.C})\ \% \quad (7)$$

Where F.C. is the fixed carbon content of the briquette, %

M.C = the moisture content of the briquette, %

V.M = the volatile matter of the briquette, %

A .C = the ash content of the briquette, %

2.6. Combustion Properties

2.6.1 Calorific Value

The calorific value of the briquettes was determined using the values of fixed carbon and volatile matter from the proximate analysis, as per Chirchir et al. (2013) and Kimutai and Kimutai (2019). The calorific value of the briquette is given by equation 8.

CV = 2.326 (1476FC + 144VM)/1000 (8)

Where:

CV = calorific value of the briquette (MJ/kg)

FC = fixed carbon Content (%)

VM = Volatile matter, (%)

2.6.1 Burning Rate

In the present study, the burning rate of the briquette was determined by measuring the mass of the briquette lost and the total time taken to burn off 100g of the briquette, placed on an insulated wire gauze of a Bunsen burner, as described by Onukak *et al. (*2017). The mass loss per unit time was calculated using Equation 9.

$$B.R = (M_{12} - M_{13})/\mathrm{t} \quad (9)$$

Where;

B.R is the burning rate (g/min)

M_{12} = initial weight of briquettes before burning (g)

M_{13} = initial weight of briquettes after burning (g)

T = total burning time, min.

2.6.2 Ignition Time

The time taken to ignite a 100g mass of the briquette placed on a wire gauze of a burner was determined using Equation 10, proposed by Onukak et al. *(*2017).

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$$T = t_1 - t_0 \quad (10)$$

Where;

t_1= time taken for the briquette to ignite, min,

t_0 = time the burner was lighted, min

T = Ignition time, min

III. RESULTS AND DISCUSSIONS

3.1 FUEL AND COMBUSTION PROPERTIES

The briquettes produced were laid out on a flat, sealed, and well-ventilated surface for 14 days to achieve a stable moisture content. Afterward, they underwent laboratory analysis to determine the fuel and combustion properties of the briquettes. The briquette produced was characterized for its physical and mechanical properties, such as relative density and shatter index; fuel properties, including ash content, moisture content, fixed carbon content, and volatile matter; and combustion properties, including calorific value, Ignition timing, and Burning rate. Tables 1-3 illustrate the mean values of the mechanical, fuel, and combustion properties of the investigated coffee husk briquette samples.

3.2 Mechanical Properties

The relaxed density of briquettes produced increases as the composition of the starch binder increases from 0% to 20% as shown in Table 1. The 80:20 coffee husk–cassava starch mix gave the highest relaxed density of 671.2 kg/m^3followed by 90:10 and 100:00 mixes, which gave the mean values of 699.6 kg/m^3 and 667.4 kg/m^3, Respectively. As shown in Figure 1, the increased relaxed density indicates an improved energy density and enhanced combustion performance with an increased starch ratio in the briquette. The result obtained for relaxed density is comparable to that obtained by Aaliah et al (2023), who reported relaxed density values about 0.41 - 0.76 g/m^3Composite briquette using coffee husk, corn cob, and starch binder ratio increases from 0% to 75%. Thus, briquettes with better combustion properties, like relaxed density, can be produced by increasing the binder ratio in the briquette.

The Shatter Index of briquettes has the highest value for briquettes with a 20% binder ratio and the lowest for briquettes with 0% binder ratio. The result of the shatter index, as shown in Table 1, indicates that briquettes with a higher proportion of starch binder retain their original structure better when dropped or collapsed from a certain height above the ground. The variation of the Shatter index with increasing starch ratio is illustrated in Figure 2. The estimated Shatter index indicates possible damage that the coffee husk briquette might be subjected to during transportation and utilisation.

The water resistance of the briquette increases as the starch binder ratio increases from 0% to 20%, as shown in Figure 3. The increase in water resistance value is due to the reduction in the rate of water reabsorption, as the particles of the briquette binder bind more firmly together with increasing binder ratio from 0% to 20%.

Table 1: Density, Water Index, and Shatter Index of the coffee husk Briquette

Husk Mix	Relaxed Density ()m³m^3)	Water Resistance (%)	Shatter Index (%)
CH 0	667.4	74.5	84.5
CH 2	669.6	78.2	85.2
CH 3	675.2	81.3	86.4

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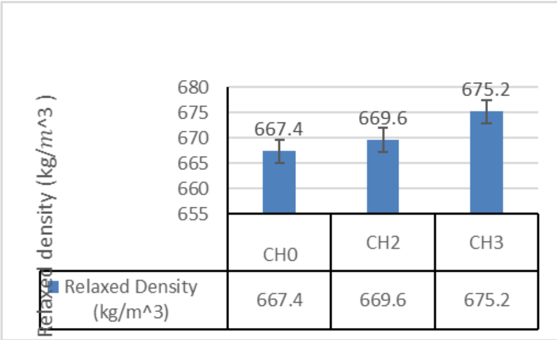

Fig.1: Variation of Relaxed Density with Briquette binder ration

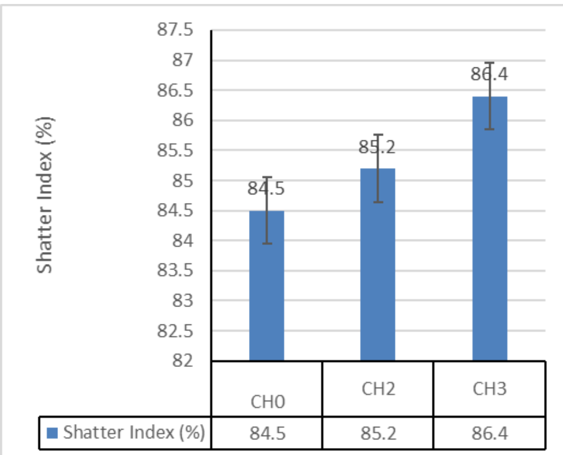

Fig.2: Variation of Shatter Index with briquette binder ratio

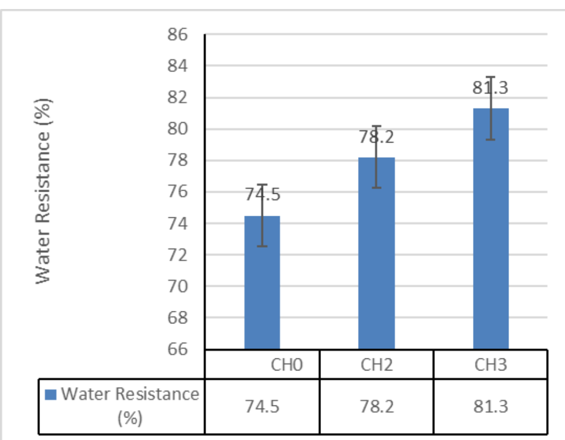

Fig. 3: Variation of Water Resistance with Briquette Binder Ratio

3.3 Proximate analysis

Table 2 presents the proximate analysis results for briquettes without binder, as well as those with 10% and 20% binder. The moisture content of the briquette decreases as the ratio of starch increases in the mix. This results in reduced moisture reabsorption as the ratio of starch increases in the mix. The coffee husk briquette in this study showed lower MC than leaves and vegetable (12.79%) and wood waste (9.40%), and higher as compared to bones(3.58%), food waste (5.9%) % and fruit waste (8.5%) as reported by Belayneh (2019) and Rominiyi *et al.* (2017).

Results indicate that the volatile matter of the briquette reduces as the ratio of the starch binder increases from 0% to 20%; the volatile matter was high for the sample without a binder compared to the samples with a binder. The sample without binder gave the highest ratio of volatile matter value of 27.40% compared to other samples with

volatile matter of 26.02% and 25.84% corresponding to 10% and 20% binder, respectively, as shown in Figure 4. As the starch ratio increases, reduced volatile matter implies that briquettes with 10% and 20% starch ratios will burn with less smoke flame during combustion, making the combustion easy to control.

The amount of fixed carbon was 58.14%, 59.48%, and 59.74% for the samples with no binder, 10% binder, and 20% binder ratios, respectively. This shows that the briquette's fixed carbon content increases as the starch binder's ratio increases from 0% to 20%. This result agrees with that of Sotannde et al. (2010) and Zapusek et al. (2003), who reported an increasing heating value of the briquette and an enhanced smokeless flame as the fixed carbon content of the briquette increases.

The result of the ash content of the briquette (Figure 4) shows that an increase in the binder ratio reduces the ash produced when the briquettes are burnt. Adding a binder to the samples results in the complete combustion of the briquette, making a smaller amount of ash during the combustion process. The ash content of the briquette reduces as the starch ratio in the briquette increases from 0% to 20%.

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3.4 Combustion Properties

Results shown in Table 3 indicate that the calorific value of the briquettes increases with an increase in binder content. The higher heating value of 29.08 MJ/kg obtained in briquettes with a 20% binder ratio, compared to 28.90 MJ/kg obtained in binder-less briquettes, could be attributed to the higher density, volatile matter, fixed carbon, and lower ash content resulting from the difference in the coffee husk-to-starch binder ratio (Figure 5). This was higher than the value of 17.8 MJ/kg reported for firewood by Belayneh (2019) and the average of 23.0MJ/kg and 15.90-16.60MJ/kg reported by Lubwama and Yiga (2018) for coffee husk and rice husk, respectively. The high calorific value obtained for the samples could be attributed to the high lignin level in coffee husk due to lignin's extractive and bonding effects on the heating value.

Table 2: Proximate Analysis of the coffee husk Briquette

Husk-Starch Mix	Moisture (%)	Volatile Matter (%)	Ash Content (%)	Fixed Carbon Content (%)
CH0	7.24	27.40	7.71	57.65
CHS1	7.18	26.02	7.32	59.48
CHS2	7.14	25.84	7.28	59.74

In this study, the ignition time is higher in the 20% starch ratio than in the 10% ratio, and it also occurs in the briquette without binder when using small quantities of additional fuels, such as kerosene or gas. The highest ignition time of 313.5 s, as shown in Table 3, was observed in sample CH2 with a 20% starch binder. Sample CH2 with a 10% starch binder had an ignition time of 295.7 s. Sample CH0 has the shortest ignition time of 282.4 s due to the higher volatile matter of the briquette composition (Figure 6).

The result in Table 3 shows that the briquette CH0 with a starch ratio of 20% has the highest burning rate, 2.78 kg/min, followed by CH1briquette with a 10% starch ratio of 2.58 kg/min, and the lowest value of 2.64 kg/min for the briquette

without binder. This is because the volatility of the briquette, which is a prime function of burning rate, decreases as more starch binder is added in other samples with a higher proportion of starch. (Figure 7)

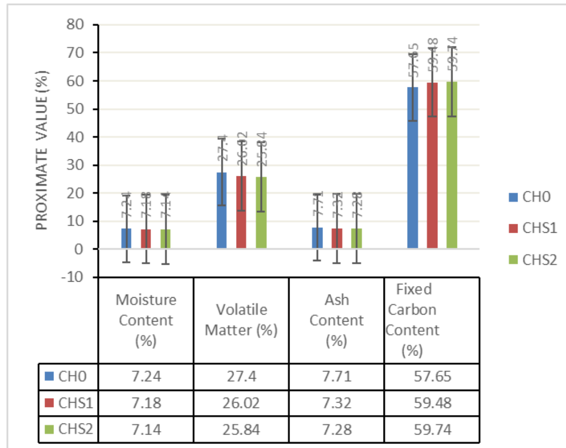

Fig.4: Effects of binder ratio on the Moisture content, Volatile matter, Ash content, and fixed carbon content.

Table 3: Combustion Properties of the coffee husk Briquette

Husk-Starch Mix	Caloric Value(MJ/Kg)	Ignition Timing (s)	Burning Rate (Kg/min)
CH0	28.90	282.4	2.78
CHS1	29.05	295.7	2.53
CHS2	29.08	315.3	2.64

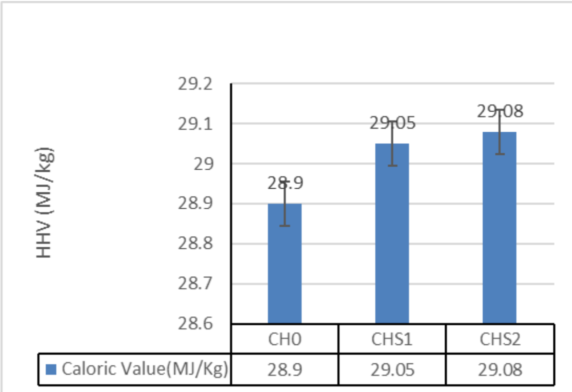

Fig.5: Effects of Binder Ratio on Calorific Value of the produced Briquette.

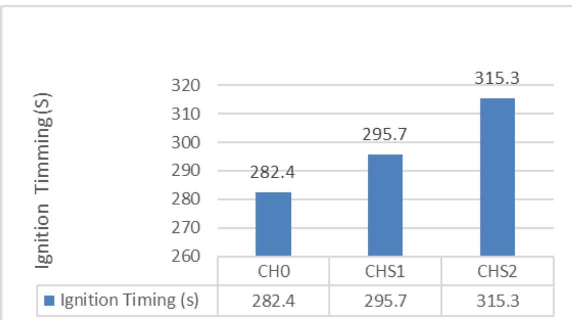

Fig.6: Effects of Binder on Ignition Time of the produced Briquette.

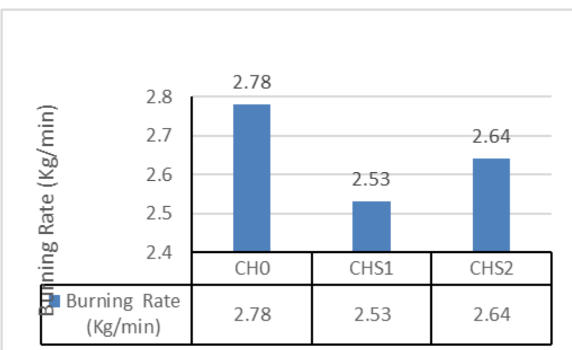

Fig.7: Effects of binder ratio on burning rate of the produced briquette.

IV. CONCLUSION

The study's findings revealed that the energy content of coffee husk briquettes using a starch binder ranges between 28.90 MJ/kg, obtained in a binder-less briquette, and 29.08 MJ/kg, obtained in a 20% binder briquette. The results indicate that a reasonably high heating value can be achieved with coffee husk briquettes, even without a binder, compared to a briquette produced with a binder such as cassava starch. The briquettes, with a maximum heating value of 29.08 MJ/kg, serve as a substitute for firewood because they are very close to that of ordinary wood charcoal (31.38 MJ/kg). It can be concluded that coffee husk has high potential as a source of renewable and environmentally friendly energy, thereby reducing pollution and providing a sustainable option for managing coffee waste.

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