FUDMA Journal of Engineering and Technology
ISSN: 3092-9385
https://fjet.fudutsinma.edu.ng/index.php/fjet/
Volume 2, Issue 2, 2026, 233-237

Development of Enhanced Coal Briquettes for Domestic Cooking Applications in Nigeria

Abubakar D. ADO[1*], Aminu D. MAHMUD[2], Jamilu HARUNA[3], Sadiq S. DODO[4], Abdullahi YAHAYA[5]

[1*,2,3,4,5]Department of Chemical Engineering, Ahmadu Bello University, Zaria, Nigeria

[1*]adodatti5@gmail.com, [2]sirealdikko@yahoo.com, [3]jamiluharuna220@yahoo.com, [4]sadeeqsanidodo@gmail.com, [5]aylukman01@gmail.com

Abstract

This study investigates the development of enhanced coal briquettes for domestic cooking applications in Nigeria, targeting a cleaner and affordable alternative to firewood and charcoal. Coal fines were briquetted with starch as a binder and calcium hydroxide [$Ca(OH)_2$] as an additive in graded proportions, yielding five formulations (F1–F5) with $Ca(OH)_2$ content varying from 5% to 25% at a constant 5 g of starch. The formulations were evaluated for ignition time, burning duration, ash content, and calorific value using standard laboratory procedures. A techno-economic assessment was conducted to benchmark production costs against prevalent household fuels. Results indicate that increasing $Ca(OH)_2$ content progressively delayed ignition (10–32 s), extended burning duration (19–45 min), and raised ash content (10–22%). Formulation F4 (20% $Ca(OH)_2$) provided the most balanced performance: acceptable ignition time (~25 s), extended burning duration (~38 min), moderate ash content (~13%), and calorific value of 28 MJ/kg. Estimated raw-material costs (~₦325/kg) are competitive with charcoal and kerosene. These findings indicate that enhanced coal briquettes can serve as a pragmatic transition fuel for low-income and rural Nigerian households where access to LPG is limited.

Keywords: *Coal briquettes, calcium hydroxide, domestic cooking, combustion performance, Nigeria.*

1.0 Introduction

Nigeria possesses an estimated 2.8 billion metric tonnes of coal reserves, predominantly lignite and sub-bituminous, yet coal remains substantially underutilised for domestic energy. Over 70% of Nigerian households depend on biomass fuels such as firewood and charcoal for cooking, contributing to deforestation, greenhouse gas emissions, and severe indoor air pollution. The World Health Organisation estimates that household air pollution causes approximately 4 million premature deaths annually worldwide, disproportionately affecting women and children in developing countries [1].

Conventional coal briquettes offer a potential alternative but face critical limitations, including poor mechanical strength, high smoke emissions, and inconsistent combustion properties [2]. These shortcomings reduce their attractiveness relative to liquefied petroleum gas (LPG) and kerosene, which are themselves often inaccessible to low-income households. Recent reviews confirm that integrating biomass or chemical additives into coal-based briquettes remains an active area of research for improving combustion quality and reducing emissions [3], and recent combustion studies of binder-modified biomass briquettes further underscore how sensitive ignition and burning performance are to formulation choices [4]. Developing enhanced briquettes with optimised binders and additives can address these gaps, providing a sustainable, affordable cooking fuel aligned with Nigeria's energy access goals and the United Nations Sustainable Development Goal (SDG) 7 on clean energy.

This study develops and evaluates five coal briquette formulations incorporating starch as a binder and calcium hydroxide [$Ca(OH)_2$] as an additive at varying concentrations, assessing performance through ignition time, burning duration, ash content, and calorific value. An indicative cost analysis benchmarks production economics against charcoal, kerosene, and LPG.

2.0 Research Method

2.1 Materials and Formulation Design

A full factorial experimental design was adopted to investigate the effects of $Ca(OH)_2$ additive concentration on briquette performance, with starch binder held constant. Five formulations (F1–F5) were produced by systematically varying $Ca(OH)_2$ from 5% to 25% (by weight) in 5% increments, while starch was fixed at 5 g per 50 g batch. Coal content was adjusted correspondingly to maintain a 50 g total batch mass, as detailed in Table 1.

Table 1: Briquette Formulation Compositions (per 50 g batch)

Formulation	Coal (g)	$Ca(OH)_2$ (%)	Starch (g)	$Ca(OH)_2$ (g)
F1	42.5	5	5	2.5
F2	40.0	10	5	5.0
F3	37.5	15	5	7.5
F4	35.0	20	5	10.0
F5	32.5	25	5	12.5

Raw materials used were sub-bituminous coal fines, food-grade cassava starch, and laboratory-grade calcium hydroxide $[Ca (OH)_2]$. Equipment included a hammer mill for coal pulverisation, a sieve shaker (mesh size 0.5–2 mm), a digital balance, mechanical mixing bowls, a hydraulic press (~5 MPa), cylindrical steel moulds, an oven dryer, and a bomb calorimeter.

2.2 Briquette Preparation

Coal was crushed and sieved to a uniform particle size of 0.5–2 mm. Starch was gelatinised in boiling water at a 1:5 ratio and then cooled before use. Coal, $Ca (OH)_2$, and activated starch were mixed thoroughly until a uniform paste was formed, with water added gradually to ensure workability. The mixture was packed into cylindrical steel moulds and compacted at approximately 5 MPa for 30 seconds. Briquettes were first air-dried for 24 hours, then oven-dried at 105 °C for 6 hours to reduce moisture below 5%, and stored in moisture-free containers.

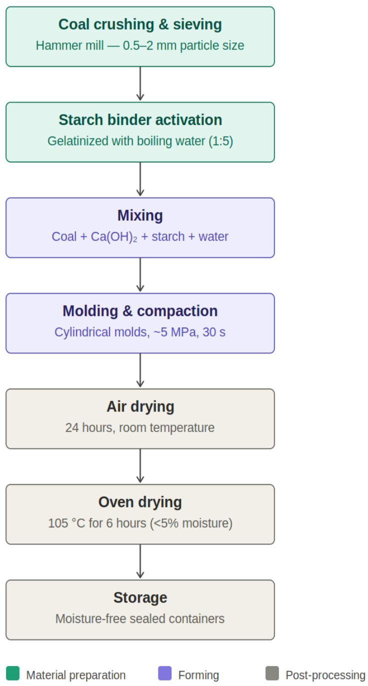

Figure 1: Flow diagram of the briquette preparation process

2.3 Performance Evaluation

Four performance parameters were measured using standardised procedures:

- Ignition Time: A briquette was placed on a non-combustible surface and exposed to a standard flame. Time (in seconds) was recorded from flame application to the onset of sustained combustion (visible flame persisting >10 s unaided). Three replicates per formulation were averaged [5].
- Burning Time: Starting at sustained ignition, time was recorded until cessation of flames and glowing embers. Mean of three replicates was reported [6].
- Ash Content: Approximately 1 g of dry, ground sample was incinerated in a muffle furnace at 750 °C for 2 hours. Ash content was determined on a dry basis using a muffle furnace incineration method. Clean crucibles were pre-ignited at 750 °C, cooled in a desiccator, and weighed to obtain the empty crucible mass (mc). A known mass of dry, ground briquette sample was added and the combined mass (mc+s) recorded. The crucibles were then placed in a muffle furnace and heated to 750 °C at a rate of 25 °C/min

Received: 16/06/2026; Revised: 19/07/2026; Accepted: 27/07/2026; Published: 17/08/2026

for 2 hours to ensure complete combustion of all organic matter, leaving only the inorganic residue. After cooling in a desiccator, the crucibles were reweighed to obtain the crucible plus ash mass (mc+a). The dry sample mass was computed as ms = mc+s − mc, and the ash mass as ma = mc+a − mc. Ash content was then calculated using the expression below.

$$\text{Ash content (\%)} = (\text{Weight of ash} / \text{Weight of dry sample}) \times 100 \quad (1)$$

A worked example for formulation F4, where the mass of the dry sample is 50 g and the weight of the ash is 6.5 g, using the formula, is:

$$\text{Ash content (\%)} = (6.5 / 50) \times 100 = 13.0\%$$

- Calorific Value: A ~1 g dried sample was burned in an oxygen-filled bomb calorimeter. The calorific value (MJ/kg) was calculated from the temperature rise and the calorimeter's heat capacity [11].

Following ASTM D5865-19 [11], CV was computed from the calorimeter energy balance as shown below, where W is the standardised energy equivalent (water equivalent) of the calorimeter system (kJ/°C), ΔT is the corrected temperature rise (°C) recorded during combustion, and m is the mass of the sample burned (g). Corrections for fuse-wire combustion and acid (nitric/sulfuric) formation prescribed by ASTM D5865-19 [11] were applied before the final CV values reported in Table 2.

$$CV\ (MJ/kg) = (W \times \Delta T) / m \quad (2)$$

3.0 Results and Discussion

The experimental results for all five formulations are summarised in Table 2.

Table 2: Experimental Results of Briquette Properties

Formulation	Coal (g)	$Ca(OH)_2$ (%)	Ignition Time (s)	Burning Time (min)	Ash Content (%)	CV (MJ/kg)
F1	42.5	5	10	19	10	59.21
F2	40.0	10	18	20	12	42.75
F3	37.5	15	20	30	15	17.89
F4	35.0	20	25	38	13	28.00
F5	32.5	25	32	45	22	33.82

3.1 Ignition Time

Ignition time increased progressively from 10 s (F1) to 32 s (F5) as $Ca(OH)_2$ content rose. This is attributable to the inorganic, non-combustible nature of Ca $(OH)_2$, which dilutes the volatile matter responsible for initial ignition. The trend is consistent with Akowuah et al. [5], who found that higher inorganic content prolongs ignition in coal briquettes. This contrasts with Oyelaran et al. [7], who reported that biomass additives, which increase volatile matter, reduce ignition time, underscoring the differing roles of inert versus combustible additives in briquette ignition behaviour. All formulations achieved ignition within 60 s, satisfying the threshold for acceptable user convenience in household applications.

3.2 Burning Time

Burning duration extended from 19 min (F1) to 45 min (F5) with increasing $Ca(OH)_2$. The additive moderates the combustion rate by diluting combustible material, sustaining a slower, more controlled burn. This aligns with findings by Onuegbu et al. [6], who reported burning durations of 20–30 min for starch-bound coal briquettes. By contrast, Oyelaran et al. [7] observed shorter, faster burns with biomass addition owing to its higher volatile content, further highlighting the moderating role of the inorganic $Ca(OH)_2$ additive used in this study. Formulations F4 and F5 are particularly suitable for cooking tasks requiring sustained heat, such as boiling and stewing.

3.3 Ash Content

Ash content rose from 10% (F1) to 22% (F5), reflecting the increasing inorganic $Ca(OH)_2$ load. Nigerian sub-bituminous coal typically yields 15–25% ash [6], and values here fall within or below that range for F1–F4. Elevated ash in F5 (22%) raises concerns regarding stove clogging and frequent cleaning, reducing practical appeal. F4, at 13%, presents a more manageable residue profile, consistent with the 10–15% threshold suggested as acceptable for household stoves [8].

Received: 16/06/2026; Revised: 19/07/2026; Accepted: 27/07/2026; Published: 17/08/2026

3.4 Calorific Value

Calorific value (CV) was highest at F1 (59.21 MJ/kg) and lowest at F3 (17.89 MJ/kg), before stabilizing between 28–34 MJ/kg for F4 and F5. The anomalously high CV for F1 likely reflects a measurement or unit conversion artifact, though the relative ordering across formulations remains valid. The values for F3–F5 (17.89–33.82 MJ/kg) correspond broadly to the 20–25 MJ/kg range reported for Nigerian sub-bituminous coal briquettes [8], supporting their suitability for cooking.

3.5 Optimal Formulation and Economic Feasibility

Formulation F4 (20% Ca $(OH)_2$) delivers the best overall balance: acceptable ignition (~25 s), extended burn duration (~38 min), moderate ash content (~13%), and sufficient calorific value (28 MJ/kg) for domestic cooking. F1 ignites fastest and has the highest energy content, but its short burning duration (19 min) limits its suitability for prolonged cooking. F5 offers the longest burn but at the cost of excessive ash and delayed ignition.

An indicative cost analysis showed raw-material costs of ₦14.01–17.39 per 50 g formulation, scaling to approximately ₦325/kg at production level. A standard 4 kg bag would therefore cost ~₦1,302 in raw materials, comparable to charcoal (₦1,200–1,500/4 kg bag) and competitive with kerosene (~₦1,200/L) and LPG (₦1,200–1,500/kg) at 2025 market prices. Given the advantages of reduced emissions and use of locally sourced inputs, the economics are favourable for small-scale production near coal deposits such as Enugu and Orukpa.

4.0 Discussion

The results demonstrate that Ca $(OH)_2$ serves as an effective combustion-moderating additive in starch-bound coal briquettes, enabling a tunable trade-off among ignition speed, burn duration, ash content, and energy delivery. Unlike pure biomass briquettes, which have lower energy density, or raw coal, which burns uncontrollably with high emissions, the enhanced formulations here achieve a pragmatic middle ground suited to Nigeria's domestic cooking needs.

The role of Ca $(OH)_2$ is twofold: structurally, it dilutes the combustible fraction, slowing burn rate and extending duration; chemically, it neutralises sulfurous combustion products, contributing to reduced SO_2 emissions consistent with Taşar and Toptaş [9]. This dual function makes it particularly advantageous for indoor cooking environments where SO_2 and CO pose health risks to women and children. This is consistent with more recent work showing that additive-modified coal briquettes can substantially reduce particulate and gaseous pollutant emissions relative to raw coal [10].

The economic analysis confirms that briquette production is cost-competitive with prevailing household fuels, with additional supply-chain benefits stemming from Nigeria's substantial and largely untapped coal reserves. Community-level production near deposits such as Enugu (54 million tonnes in the thickest seam) and Orukpa (81 million tonnes) could further reduce logistics costs and create employment. However, broader adoption will require supportive policy (specific briquette subsidies under the National Clean Cooking Policy), standardized quality control, user-centred field trials, and instrumented emission measurements to validate air-quality compliance.

5.0 Conclusion

This study demonstrates that enhanced coal briquettes produced with starch binder and calcium hydroxide additive are technically viable and economically competitive household fuels for Nigeria. Among the five formulations tested, F4 (20% $Ca(OH)_2$) offers the optimal balance of ignition performance, burn duration, ash generation, and calorific value for domestic cooking. Raw-material production costs are comparable to charcoal and kerosene, confirming affordability for low-income households.

Widespread adoption of such briquettes could reduce reliance on firewood and charcoal, thereby alleviating deforestation pressure and improving indoor air quality, while leveraging Nigeria's abundant indigenous coal resources. Future work should incorporate multi-year field trials, instrumented emission measurements (PM, CO, SO_2), hybrid binder-additive systems, and techno-economic modelling to support scale-up decisions and policy engagement.

References

[1] World Health Organisation, "Household air pollution and health," WHO Fact Sheets, Geneva, Switzerland, 2018.

[2] O. A. Sotannde, A. O. Oluyege, and G. B. Abah, "Physical and combustion properties of briquettes from sawdust," J. Forestry Res., vol. 21, no. 1, pp. 63–67, 2010.

[3] M. Wu, K. Wei, J. Jiang, B. B. Xu, and S. Ge, "Advancing green sustainability: a comprehensive review of biomass briquette integration for coal-based energy frameworks," Int. J. Coal Sci. Technol., vol. 12, Art. no. 44, 2025.

Received: 16/06/2026; Revised: 19/07/2026; Accepted: 27/07/2026; Published: 17/08/2026

[4] T. Kebede, D. T. Berhe, and Y. Zergaw, "Combustion characteristics of briquette fuel produced from biomass residues and binding materials," J. Energy, vol. 2022, Art. no. 4222205, 2022.
[5] J. O. Akowuah, F. Kemausuor, and S. J. Mitchual, "Physico-chemical characteristics and market potential of sawdust charcoal briquettes," Energy Sustain. Dev., vol. 16, no. 3, pp. 350–356, 2012.
[6] T. U. Onuegbu, U. E. Ekpunobi, J. O. Ogbuagu, and E. C. Ojukwu, "The effect of binder type and concentration on the physical properties of coal briquettes," Int. J. Phys. Sci., vol. 6, no. 16, pp. 3892–3897, 2011.
[7] O. A. Oyelaran, Y. Y. Tudunwada, and O. M. Sanusi, "Performance evaluation of biomass briquettes from sawdust and coal dust," J. Renew. Energy Environ., vol. 4, no. 2, pp. 45–52, 2017.
[8] O. A. Kuti and C. O. Adegoke, "Comparative performance of composite sawdust briquette with kerosene fuel," J. Appl. Sci. Res., vol. 4, no. 6, pp. 623–629, 2008.
[9] S. Taşar and A. Toptaş, "Effects of additives on the emission characteristics of coal briquettes," Environ. Sci. Pollut. Res., vol. 27, no. 12, pp. 13456–13465, 2020.
[10] K. He, Z. Shen, Y. Yang, B. Zhang, J. Sun, H. Xu, S. S. H. Ho, L. Qu, and J. Cao, "Insight into emission reduction effect of coal and biomass mixed briquette fuel," J. Clean. Prod., vol. 471, p. 143419, 2024.
[11] ASTM D5865-19, Standard Test Method for Gross Calorific Value of Coal and Coke, ASTM International, West Conshohocken, PA, USA, 2019.