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Design and Fabrication of a Briquette-Fueled Stove for Integration with Fish Smoking Kilns

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Abstract

The transition toward clean, sustainable biomass energy systems is critical to mitigating the environmental and health impacts of traditional fish smoking practices. Briquettes, derived from renewable agricultural residues, offer a low-emission alternative with promising thermal performance in artisanal and semi-industrial settings. This study presents the design, fabrication, and performance evaluation of a briquette-fueled stove developed for integration with fish smoking kilns. The stove was constructed using locally available materials and featured thermally insulated walls, an ash collection chamber, and a variable-speed air blower for controlled combustion. Three insulation materials—clay, fiber, and sawdust—were comparatively tested under a range of blower speeds using the standardized Water Boiling Test (WBT) protocol. An expanded experimental matrix was implemented with blower speeds of 50, 75, and 100 rpm applied to each insulation type to examine heat retention and combustion dynamics. Boiling time data were statistically analyzed using ANOVA and standard deviation metrics to validate performance differences. The fiber-insulated variant consistently exhibited the highest thermal efficiency, achieving boiling in 15.0 ± 0.6 minutes at 100 rpm. In contrast, clay insulation required up to 30.1 ± 0.9 minutes, and sawdust insulation yielded intermediate results. Lifecycle cost and material durability assessments indicate that fiber-based insulation, despite slightly higher upfront cost, offers long-term savings due to reduced heat loss and better structural resilience. Detailed schematics are provided to ensure reproducibility and technical transferability. Overall, the briquette-fueled stove provides an efficient and scalable solution for sustainable fish smoking operations, particularly in rural and resource-constrained environment

Keywords: One health, aquatic toxicity, phytochemicals, post-treatment, plant

Introduction

The accelerating growth in global population and urbanization has intensified the demand for affordable and sustainable energy sources, particularly in developing countries. Presently, fossil fuels contribute over 80% of the global primary energy supply (Sansaniwal et al., 2017), yet their domestic use, especially for cooking, heating, and fish processing; remains a leading contributor to greenhouse gas emissions and indoor air pollution (Tursi, 2019). In many rural and peri-urban regions of sub-Saharan Africa, fish processors and households continue to rely heavily on traditional biomass fuels such as firewood, charcoal, and agricultural residues. This dependence not only accelerates deforestation but also exposes users to respiratory illnesses and long-term environmental degradation (Annenberg et al., 2013; MacCarty, 2010).

Fish smoking is a culturally and economically significant food preservation method in tropical regions where cold-chain infrastructure is limited. The process involves controlled thermal dehydration and smoke treatment to extend shelf life, improve flavor, and ensure microbial safety (Olorunnisola, 2007; Ofem Odey, 2022). However, traditional smoking kilns—typically fueled by firewood—are characterized by high fuel consumption, low thermal efficiency, and exposure to toxic emissions. This calls for the integration of modern, energy-efficient technologies such as briquette-fueled stoves that offer controlled combustion, improved insulation, and reduced emissions. Biomass briquettes, derived from organic waste such as rice husks, coconut shells, corn cobs, and groundnut shells, are renewable, biodegradable, and carbon-neutral (Oladeji, 2010; Muazu Stegemann, 2015). When manufactured under proper conditions, briquettes demonstrate high thermal efficiency and clean combustion. These properties make them an attractive substitute for firewood in fish smoking and other agro-processing tasks, particularly in communities with limited access to conventional energy.

Despite advancements in briquette production and stove design, adoption remains limited due to several factors. Many previous stove initiatives failed due to ergonomic mismatches, complex user interfaces, and cultural misalignment with local cooking practices (Orhevba Chinedu, 2015; Begum, 2016). Poor stove performance, inflexible combustion chambers, and incompatible fuel geometries further discouraged widespread use. Recognizing this, the current study incorporates feedback from community-level consultations and co-design workshops to tailor the stove to the needs of local fish processors, particularly women, who are the primary users of such stoves in most settings. This study presents the design, fabrication, and evaluation of a briquette-fueled stove engineered for integration with traditional fish smoking kilns.

MATERIALS AND METHODS

Design Considerations

The design of the briquette-fueled stove for integration with fish smoking kilns was guided by multiple technical, economic, and user-centered criteria to ensure optimal performance, safety, and affordability. The key considerations are as follows:

Thermal Efficiency: Maximizing thermal efficiency was a primary objective, focusing on effective convective heat transfer from combustion gases to the cooking or smoking vessel. To minimize heat loss, the pot-to-flame gap was reduced, and materials with low thermal mass, such as mild steel, were selected for the stove body. Additionally, thermal insulation using materials like glass fiber, refractory clay, or sawdust was incorporated to retain heat within the combustion chamber and reduce fuel consumption.

Ash Removal: An integrated ash collection system was included to enhance combustion stability. Located at the base of the stove, the chamber allows ash to fall away from the combustion zone by gravity, preventing blockage and improving airflow during operation.

Ease of Fabrication and Maintenance: The stove's configuration was intentionally simplified to allow for local fabrication using readily available tools and materials. The design supports ease of maintenance and is suitable for both household and small-scale commercial use.

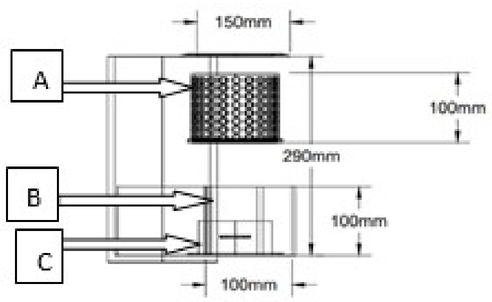
Regulated Airflow System: A single-phase variable-speed blower was incorporated to provide controlled airflow, enhancing combustion efficiency. This fan-assisted air supply ensures a higher burning rate and supports prolonged combustion, particularly necessary during extended smoking cycles.

Cost-Effectiveness: Cost considerations guided the selection of materials and fabrication methods to ensure affordability for low-income households. The stove was constructed using locally sourced materi-

als, significantly reducing both production and maintenance costs.
Portability: Portability was addressed by designing a compact and lightweight stove, allowing for ease of transport and repositioning in both indoor and outdoor environments. Safety: User safety was prioritized through the incorporation of features such as insulated walls to prevent accidental burns, strategically positioned handles, and adequate venting to prevent the accumulation of toxic gases. Safety standards were also followed throughout the fabrication process.
Durability: The combustion chamber was fabricated from heat-resistant and corrosion-resistant mild steel to ensure long-term structural integrity under continuous high-temperature use. The material selection was intended to minimize degradation due to thermal fatigue or mechanical stress. Combustion Efficiency: Efficient fuel combustion was achieved by optimizing the combustion chamber geometry and ensuring sufficient and adjustable air supply. This reduced particulate emissions and maximized heat output, contributing to cleaner and more effective energy conversion.
The stove was constructed using locally sourced materials, and designed to include insulated walls, a variable-speed blower powered by a 220 V AC motor, and an ash removal system. The blower's energy demand is minimal (rated ¡150 W) and operational cost analysis confirms its affordability for rural users. The experimental framework evaluates three insulation materials (clay, fiber, and sawdust under multiple blower speeds (50, 75, and 100 rpm)) using the standardized Water Boiling Test (WBT). Performance metrics such as boiling time, thermal retention, and fuel consumption were statistically validated using ANOVA and standard deviation analysis. Additionally, lifecycle durability and cost-effectiveness of each insulation type were assessed to inform long-term usability in field settings.

Description and fabrication of Briquette stove parts

The front view of the briquette stove and the top view of the combustion chamber are shown in Figure 1 and 2 below. It is cylindrical in shape and it consists of three compartments, which are; combustion chamber, ash pit and air circulation unit.



A-Combustion chamber; B-Air circulation; C-Ash pit

Figure 1: Front view of the briquette stove

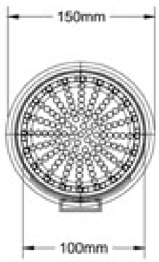


Figure 2: Top view of the combustion chamber

Figure 3: The fabricated stove

Figure 4: Briquette used in testing of Stove

Operation of a briquette stove

Fuel briquette is loaded from the top of the stove into the combustion chamber, the fuel briquette was suitably placed in the combustion chamber with the flat base resting on the separating grate to facilitate better air draft and more efficient combustion of the briquettes. The briquette was lit with fire and kerosene. 2.4.1 Water Boiling Test (WBT) The fabricated briquette stove was used for water boiling test The water boiling point test was carried out to evaluate the thermal performance of the stove. This was achieved in three phases which consists of; bringing water to a boil from a cold start, bringing water to a boil when the stove is hot, and keeping the water's temperature at a moderate level. In this test, the time it takes a given quantity of fuel (i.e., briquette) to heat and boil water was recorded. The briquette used was first weighed before pouring a 1000ml of water into a cooking pot. The briquette in the stove was ignited and as soon as the flame was stabilized after 5mins, the pot containing the water to be tested was placed on the stove. A stopwatch was used to read the time taken to boil the water. The initial temperature of the water was recorded using a thermometer throb. The boiling of the water was terminated after attaining a boiling point and the final temperature of the water was recorded according to Davies and Abolade (2013). The WBT yields numerous indicators for accessing cookstove performance, among which are thermal efficiency, specific fuel consumption of the stove, and the briquette burning rate (Anenberg et al., 2013).

Briquette Burn Rate (BR)

To determine briquette burn rate was used in this experiment according to (Onuegbu et al., 2012). A known weight of the briquette sample was ignited using a stove, the weight loss was monitored throughout the combustion process until a constant burn weight was attained. The weight reduction at a certain time was calculated using the following formula

$$B_R = \frac{Total weight of burnt briquette(kg)}{Total time taken(hrs)} \quad (1)$$

Time spent cooking per kilogram of the cooked food

Ratio of the time spent to the total weight of the cooked food.

$$\mathbf{T_s} = \frac{Total time spent in cooking(hr)}{Total weight of cooked food(kg)} \quad (2)$$

Specific Fuel Consumption (PHU)

This is referred to has the amount of solid fuel equivalent used in achieving a desired task divided by the weight of the task.

$$\mathbf{P_{HU}} = \frac{Mass of fuel consuption(kg)}{Total weight of cooked food(kg)} \quad (3)$$

Thermal Efficiency (η)

The percentage of total energy that is used profitably in any thermodynamic process is known as thermal efficiency. This is the proportion of work done by heating and evaporating water to energy used in briquette burning. According to Clarke (1985), the convective heat transfer efficiency of a cooking stove plays a significant role in how well heat is transmitted from the hot gas fuel line to the pot on the stove.

$$N_{th}(100) = Burning rate \times PHU \quad (4)$$

Statistical Analysis of Experimental Data

The data were analysed using Design Expert software. Suitable models and the best-fitting curve were established, and model adequacy was evaluated using the coefficient of determination (R^2) (Demirel and Kayan, 2012). Statistical analysis of the generated data was performed within the Design Expert environment.

Results and Discussion

Performance Evaluation

The stove was evaluated based on the rate at which the briquette burns under the application of air flowing into the stove and ability of the insulating materials to retain heat during boiling of water, the inlet air was used to determine the briquettes burn characteristics. The briquettes used were ignited by fire and supplemental fuel (kerosene) so as to ensure that the whole of the surface of the briquette ignites. The stove that was fabricated allows for three variations of stove wall which are; sawdust, clay and fiber. Results of the boiling time and the burning rate were recorded respectively. Moreover, the air flow rate and the mass of the briquette used were equally known.

Table 1: Full optimal design experiments

Run	Blower Speed (rpm)	Mass of Briquette (g)	Insulators	Boiling Time (min)	Burning Rate (g/min)
1	75	150	Sawdust	20	7.5
2	100	200	Sawdust	21	9.5
3	50	100	Clay	23	4.35
4	50	150	Fibre	21	7.14
5	100	150	Clay	22	6.82
6	75	200	Clay	25	8
7	75	150	Sawdust	22	6.82
8	50	100	Fibre	19	5.26
9	50	100	Sawdust	23	4.35
10	50	200	Clay	30	6.67
11	100	100	Sawdust	16	6.25
12	50	200	Sawdust	25	8
13	75	100	Sawdust	18	5.6
14	100	150	Fibre	18	8.33
15	100	150	Fibre	18	8.33
16	75	100	Fibre	15	6.67
17	75	150	Sawdust	20	7.5
18	100	100	Clay	20	5
19	75	200	Fibre	23	8.7
20	50	150	Sawdust	22	6.82

Boiling time

Water boiling test result from Table 3.1 showed that when using clay as an insulating material, 50rpm speed of the blower, burning a briquette fuel of 200g takes longer time to boil 1000g of water (30 mins), while the shortest time to boil 1000g of water when using clay as an insulating material takes (25 mins) at 75 rpm speed of blower burning a briquette fuel of 200g. The water boiling test result from Table 4.1 also showed that while using fibre as an insulating material, 75rpm speed of the blower, burning a briquette fuel of 200g takes longer time to boil 1000g (23 mins), while the shortest time to boil 1000g of water when using fibre as an insulating material takes (15 mins) at 75 rpm speed of the blower burning a briquette fuel of 100g. From table 4.1 the water boiling test showed that when sawdust was used as an insulating material, 50rpm speed of blower burning a briquette fuel of 200g takes longer time to boil water (25 mins), while the shortest time to boil 1000g of water when using sawdust as an insulating material takes (16 mins) at 100rpm speed of blower burning briquette fuel of 100g.

Burning rate

The result of the burning rate that occurred in a sawdust-insulated stove was 9.5 g/min and 4.35 g/min when the blower speed was 100 rpm and 50 rpm, with the mass of the briquette being 200 g and 100 g respectively. In a fibre-insulated stove, the burning rates were 8.7 g/min and 5.26 g/min at blower speeds of 75 rpm and 50 rpm with briquette masses of 200 g and 100 g respectively. Similarly, the burning rate of the fuel in a clay-insulated stove was 8.0 g/min and 4.35 g/min with blower speeds of 75 rpm and 50 rpm at briquette masses of 200 g and 100 g respectively.

A comparative analysis across the insulation types shows that sawdust provided the highest burning rate under high blower speed (100 rpm), indicating enhanced air circulation and improved combustion. Fibre insulation demonstrated relatively stable combustion performance with moderate burning rates, suggesting its potential for balancing efficiency with fuel economy. Clay insulation, although yielding the lowest burning rate at lower blower speed, showed consistency and longer burning duration, which could be advantageous in applications requiring sustained heat release rather than rapid combustion. These variations highlight the role of insulation material in influencing heat retention, combustion dynamics, and overall stove efficiency. The findings suggest that the choice of insulation should be guided by the desired application—whether rapid heating or prolonged steady burning is the priority

Interaction effect of the blower speed and the mass of briquette on Boiling time (BT)

From Equation 1, an increase in the mass of briquette and decrease in the blower speed will lead to a longer time in boiling water, while the increase in the mass of the briquette and an increase in the blower speed will lead to shorter time in boiling water. Table 2 shows that blower speed mass of briquette and the type of insulators used have a significant effect on boiling time with 0.9031 coefficient of determination (R^2).

$$BT = 21.42 - 2.09x_1 + 2.09x_2 - 0.59x_3 - 2x_3$$

where: $x_1 = BlowerSpeed$, $x_2 = MassofBriquette$, $x_3 = Insulators$(5)

Table 2: ANOVA result for boiling time

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	201.35	4	50.34	34.96	< 0.0001
	56.31	1	56.31	39.11	0.0001
	74.46	1	74.46	51.72	0.0001
	59.07	2	29.53	20.51	0.0001
Residual	21.60	15	1.44		
Cor Total	222.50	19			

Statistical parameters:
Std. Dev. = 1.20, R^2 = 0.9031, Mean = 21.05

Table 3: ANOVA result for burning rate

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	36.92	4	9.23	72.78	< 0.0001
	5.92	1	5.20	46.68	0.0001
	27.02	1	27.02	213.03	0.0001
	6.19	2	3.10	24.41	0.0001
Residual	1.90	15	0.1268		
Cor Total	38.82	19			

Statistical parameters:
Std. Dev. = 0.3561, R^2 = 0.9510, Mean = 6.88

Interaction effect of the blower speed and the mass of briquette on burning rate

From Equation 1, increase in the mass of briquette and an increase in the blower speed will yield a better burning rate, while the decrease in the mass of the briquette and decrease in the blower speed will lead to decrease in the burning rate of the fuel. Table 3 shows that blower speed, mass of briquette and the type of insulators used have a significant effect on burning rate with 0.9510 coefficient of determination (R^2).

$$BT = 7 + 0.68x_1 + 1.52x_2 - 0.17x_3 - 0.66x_3$$

Conclusion

This study successfully designed and fabricated a briquette-fueled stove tailored for integration with fish smoking kilns, addressing key limitations in traditional biomass-based energy systems. The stove incorporates performance-enhancing features such as thermal insulation, controlled air inflow, efficient ash removal, and a compact, durable structure made from locally sourced materials. Test results indicate that the design promotes faster heat transfer, improved combustion efficiency, and reduced emissions, especially when combined with optimized insulation materials like fiber. The affordability, ease of use, and adaptability of the stove make it a viable solution for low-resource communities seeking cleaner alternatives for cooking and fish processing. The innovations presented in this work contribute meaningfully to ongoing efforts in sustainable energy development and offer a scalable pathway for reducing biomass dependency and environmental degradation in artisanal food processing sectors.

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