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Review Article

Innovations in Charcoal Stove Technology: A Comprehensive Review of Efficiency and Performance

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Abstract

Charcoal stoves constitute an essential energy provision for millions residing in sub-Saharan Africa; however, conventional designs exhibit inefficiency and pose health risks, contributing to approximately 3.2 million premature fatalities each year due to household air pollution. This systematic review consolidates advancements in charcoal stove technology, with an emphasis on enhancing thermal efficiency, minimizing emissions, and ensuring user safety. Utilizing a methodologically rigorous approach, a total of 52 peer-reviewed studies (1994–2025) were meticulously examined from databases such as Scopus and ScienceDirect, employing standardized testing protocols (e.g., Water Boiling Test). The findings indicate that innovative designs, including rocket and gasifier stoves, attain thermal efficiencies ranging from 17% to 87%, in contrast to the 11% to 16% efficiencies observed in traditional models, alongside reductions in carbon monoxide emissions by as much as 75% and a decrease in fuel consumption by 70%. Nonetheless, performance outcomes exhibit variability in practical applications, influenced by user behavior and the durability of materials employed. The review emphasizes the imperative for validation through field-based studies and the development of economically accessible designs to promote widespread adoption. These technological innovations hold the potential to provide sustainable cooking solutions, thereby contributing to public health and the achievement of environmental objectives such as Sustainable Development Goal 7.

Keywords: Garri frying, semi-automated machine, cassava processing, efficiency, agro-processing innovation.

1. INTRODUCTION

Charcoal continues to serve as a fundamental component of domestic energy for billions of individuals globally (Rose *et al.*, 2022; Zulu & Richardson, 2013), particularly in regions encompassing sub-Saharan Africa, South Asia, and certain areas of Latin America (Onyenanu *et al.*, 2025). Notwithstanding international initiatives aimed at advocating for cleaner cooking alternatives, approximately 2.1 billion individuals persist in their reliance on inefficient and polluting stoves powered by solid biomass, especially in low-income and rural contexts (Chowdhury & Mostafa, 2021; Siddharthan, 2025). The combustion of charcoal within rudimentary stoves produces considerable household air pollution, which contributes to an estimated 3.2 million premature fatalities each year from strokes, chronic respiratory diseases, cardiovascular ailments, and childhood infections (Ang'u, 2023; Charity, 2020; Siddharthan, 2025). Women and children, who predominantly endure the adverse effects of cooking exposure, are disproportionately impacted, frequently inhaling concentrations of fine particulate matter that substantially exceed safe thresholds (Anaemeje *et al.*, 2022; Idogho *et al.*, 2025; Chukwudi *et al.*, 2014; Dikeogu *et al.*, 2014; Ekpechi *et al.*, 2023; Ekpechi *et al.*, 2025).

In light of these alarming realities, the advancement of innovation in charcoal stove technologies transcends a mere technical endeavor; it constitutes a critical public health and environmental necessity (Ezeaku *et al.*, 2024; Ezechukwu *et al.*, 2025; Ikebudu *et al.*, 2012; Ikebudu *et al.*, 2015; Iweka *et al.*, 2019; Iweka *et al.*, 2021a). Conventional stoves are characterized not only by their energy inefficiency but also by their high fuel consumption, thereby exacerbating forest degradation and accelerating carbon emissions (Edwards *et al.*, 2004; Miah *et al.*, 2009). The scarcity of biomass fuel, coupled with destructive harvesting methodologies, results in deforestation, soil erosion, and climate repercussions in areas such as

Kenya, where suboptimal charcoal production significantly contributes to elevated carbon dioxide emissions (I. U. Onyenanu *et al.*, 2024; Ubani & Onyenanu, 2024). Concurrently, Africa alone experiences millions of avoidable fatalities attributable to air pollution associated with cooking (Gangiah, 2022). These trends elucidate the pressing urgency and significance of enhancing charcoal stove efficiency, particularly within energy-deprived communities throughout Nigeria and the broader sub-Saharan African context (Nielsen, 2025). Over the preceding decades, engineers and researchers have transitioned stove designs from open fires or rudimentary clay pots to more advanced models that incorporate combustion and thermal dynamics principles (Ikebudu *et al.*, 2021; Offodum *et al.*, 2025; Okonkwo *et al.*, 2012; Onyenanu & Nwigbo, 2021; Onyenanu *et al.*, 2024; Owuama & Owuama, 2021). Rocket stoves, for example, are designed with insulated vertical combustion chambers that promote near-complete combustion, thereby enhancing thermal efficiency and mitigating emissions (Connell, 2025). Empirical evaluations conducted in rural Kenya revealed that rocket mud stoves resulted in a 33% reduction in kitchen carbon monoxide levels and a 42% reduction in personal exposure compared to traditional three-stone stoves (Connell, 2025). Complementary investigations in Ethiopia reported that rocket stoves achieved average thermal efficiencies of up to 32%, compared to approximately 14% for three-stone stoves, resulting in significantly reduced water-boiling times and lower specific fuel consumption (Connell, 2025). These outcomes underscore the significant performance enhancements that innovative designs can provide (Swift *et al.*, 2012; Onyenanu *et al.*, 2015; Ubani & Onyenanu, 2024; Ukwu *et al.*, 2024; Utu *et al.*, 2024; Okpala *et al.*, 2025).

Thus, this review provides a critical synthesis of recent studies on charcoal stove innovations (Ezechukwu *et al.*, 2025; Onyenanu *et al.*, 2025; Mobi *et al.*, 2013; Nwankwo *et al.*, 2025; Ajuluchukwu *et al.*, 2025; Owuama *et al.*, 2025), examining advances in design and material efficiency, combustion and thermal performance, emission reduction strategies, and their implications for household energy sustainability and public health (Nwankwo *et al.*, 2025).

2. LITERATURE AND METHODOLOGY

The body of research surrounding innovations in charcoal stoves has grown significantly over the last thirty years, focusing on aspects such as thermal efficiency, fuel consumption, emission reductions, and the socio-economic effects of enhanced designs (E. I. Nwankwo *et al.*, 2025; Onyegirim *et al.*, 2025; Onyenanu & Onyenanu, 2025; Nwigbo *et al.*, 2025). Prominent studies have utilized standardized experimental protocols, including the Water Boiling Test (WBT), Controlled Cooking Test (CCT), and Kitchen Performance Test (KPT), to assess stove performance in both laboratory and real-world settings (Obeng *et al.*, 2017; Olaoye *et al.*, 2018; Zhang *et al.*, 2018). These protocols facilitate a consistent comparison across various stove types and environments, enabling a systematic evaluation of design advancements. This review adopted a systematic literature review methodology, gathering peer-reviewed articles, technical reports, and case studies from databases like ScienceDirect, Scopus, Google Scholar, and ResearchGate (S. N. K. Onyegirim *et al.*, 2025; E. I. Nwankwo, Onyegirim, Owuama, & Ubani, 2025; S. O. Onyegirim *et al.*, 2025; I. Onyenanu, Madukasi, *et al.*, 2025; I. Onyenanu, Madu, *et al.*, 2025). Boolean search terms such as “charcoal stove efficiency,” “improved cookstoves,” “thermal performance,” and “charcoal stove emissions” were employed to identify pertinent studies, with a focus on the period from 1994 to 2025 to encompass both early efficiency assessments and recent innovations. The initial search resulted in 1,243 papers, from which inclusion criteria were applied to prioritize experimental studies with empirical data on charcoal stove efficiency, peer-reviewed articles, and conference proceedings that reported measurable outcomes like thermal efficiency, fuel consumption, or emission levels (Anyaora *et al.*, 2025; Ajuluchukwu *et al.*, 2025; Nwankwo, Onyenanu, *et al.*, 2025; Offodum *et al.*, 2025; Unya *et al.*, 2025; Ezechukwu *et al.*, 2025; Nwankwo, Onyegirim, *et al.*, 2025; Owuama *et al.*, 2025). Studies that exclusively examined fuelwood stoves, lacked methodological clarity regarding testing protocols, or were solely policy discussions without experimental evidence were excluded (S. O. N. K. Onyegirim *et al.*, 2025a; Ikebudu *et al.*, 2015; I. U. Onyenanu *et al.*, 2015; Kingsley Okechukwu Ikebudu *et al.*, 2021; Dikeogu *et al.*, 2014). Ultimately, 52 papers were deemed suitable for final analysis after a thorough screening for relevance and methodological rigor.

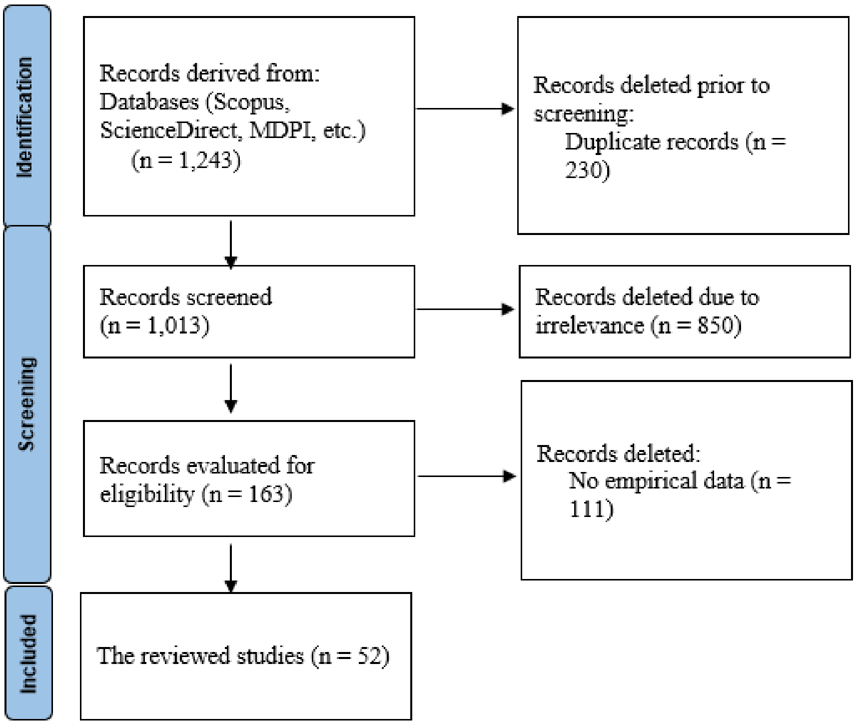

Figure 1: PRISMA Flow Diagram for the Process of Literature Selection (Source: Page *et al.*, 2021)

Publication of Journals by Ranking

Research interest in innovations and efficiency of charcoal stoves has seen a significant uptick in recent years, particularly evident in the sharp increase in publications over the last decade, as shown in Figure 2. The data indicate a strong scholarly focus on key areas such as thermal efficiency, reduction of fuel consumption, emission control, and design optimization. Remarkably, 44.3% of the analyzed studies (23 out of 52) were published between 2021 and 2025, highlighting a growing global emphasis on clean cooking technologies and their contribution to sustainable development. This trend underscores the importance of enhancing household energy efficiency and reducing emissions, especially in low- and middle-income countries where charcoal is a prevalent cooking fuel. Innovations such as rocket stoves, ceramic-lined designs, gasifier models, and hybrid charcoal stoves illustrate how technological advancements are addressing both performance and public health issues. These developments not only reflect progress in engineering research but also align with international objectives, including Sustainable Development Goal 7, which advocates for affordable and clean energy, positioning improved charcoal stoves at the forefront of discussions on energy sustainability.

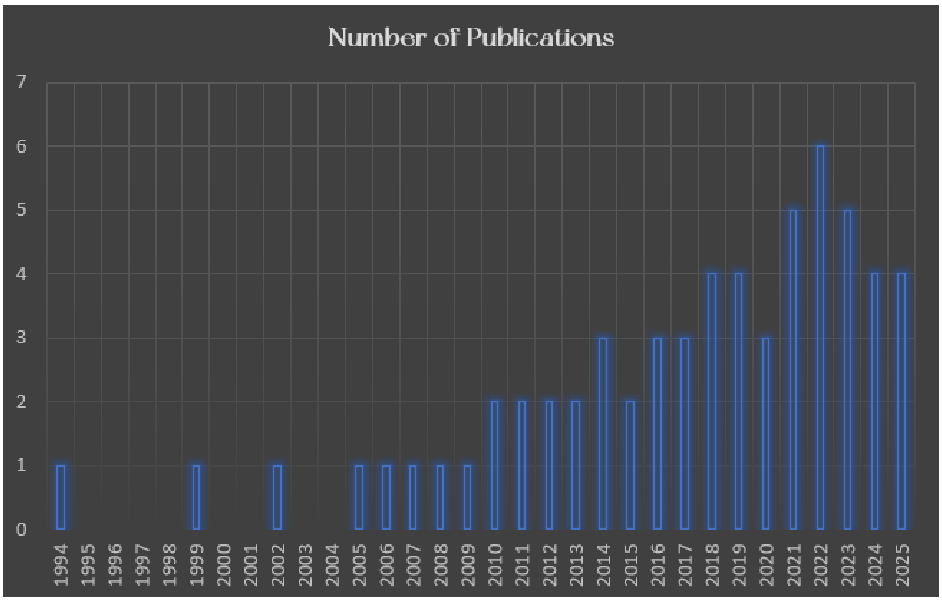

Figure 2: Graph of Journal Article by Year of Publication (Osobajo *et al.*, 2017)

3. REVIEWS

The literature review on innovations in charcoal stove design indicates a progressive enhancement in both functionality and efficiency, particularly regarding thermal performance, fuel usage, and emission management. The studies highlight a strong focus on creating stoves that not only optimize energy conservation but also support environmental sustainability and ensure user safety. Standardized testing methods, such as the Water Boiling Test and Controlled Cooking Test, have been employed to facilitate consistent performance comparisons, establishing a solid foundation for evaluation. Notably, advanced charcoal stoves generally surpass traditional models in terms of efficiency and combustion quality, with thermal efficiency varying based on design and materials. Most improved stoves exhibit marked reductions in fuel consumption and enhanced heat transfer capabilities, alongside lower emissions of harmful substances like carbon monoxide, thereby contributing to better household energy security and reduced health risks. However, while many designs show technical promise, the findings indicate that some models perform better in controlled environments than in actual household settings, underscoring the importance of user behavior and adoption for sustained efficiency. Furthermore, challenges related to durability, cost, and cultural acceptance must be addressed to maximize the impact of these innovations. A summary of these findings, including specific performance metrics and efficiency ratings for various stove designs, is provided in Table 1.

Table 1: Summary of Selected Studies on Charcoal Stove Innovations and Efficiency

Topic	Focus	Result	Citations
Thermal Performance and Emission Characteristics of Vented Charcoal Stove	The evaluation was done in order to determine its performance when compared with the commonly found charcoal stove in the locality.	The burning rate for the improved coal stove is 0.0129 kg/min, and this shows economic and efficient fuel consumption than the other stove, which is 0.0155 kg/min. The thermal efficiency of the improved stove is 17.61% while that of the local stove is 16.41%. Also, the improved charcoal stove shows better combustion efficiency of 2.3% as against 14.16% for the local stove. There is a CO reduction to an acceptable limit of the EPA for an improved stove while cooking.	(Olaoye *et al.*, 2018)
Watching the Smoke Rise: Thermal Efficiency, Pollutant Emissions, and Global Warming Impact of Three Biomass Cookstoves in Ghana	Assessment of thermal efficiency, emissions, and total global warming impact of three cookstoves commonly used in Ghana was completed using the International Workshop Agreement (IWA) Water Boiling Test (WBT) protocol.	The study results showed that, by using the Gyapa charcoal cookstove instead of the wood-burning cookstove, the global warming impact could be potentially reduced by approximately 75% and using the Gyapa charcoal cookstove instead of the coalpot charcoal cookstove by 50%. They concluded that there is a need for awareness, policy, and incentives to enable end-users to switch to, and adopt, Gyapa charcoal cookstoves for increased efficiency and reduced emissions/global warming impact.	(Obeng *et al.*, 2017)
Thermal Performance Evaluation of a Single-Mouth Improved Cookstove: Theoretical Approach Compared with Experimental Data	The thermal efficiency of a single-mouth biomass stove has been investigated using a theoretical and experimental approach.	The experimental thermal efficiency is slightly lower than the theoretical value, with a measured value of 27% compared to the theoretical value of 31.45%. The theoretical thermal efficiency can be closer to the experimental efficiency if the combustion losses caused by incomplete combustion of the fuel are considered.	(Atajafari *et al.*, 2024)
Development of Eco-Friendly Charcoal Stove	The study aimed to design, develop, and assess the performance of an 80% savings charcoal stove, which uses charcoal as its major fuel.	The thermal efficiency of the design was evaluated by the use of the water boiling test (WBT), where the useful heat was compared to the heat generated from the fuel used. Thermal efficiency of 26.4% was obtained. Hence, the developed 80% saved charcoal stove therefore has an	(Olarotimi *et al.*, 2025)

		economic advantage over regular charcoal stoves.	
Design and Performance Evaluation of Energy-Efficient Biomass Gasifier Cook Stove Using Multiple Fuels	The stove was designed to work on sawdust, wood, groundnut, and charcoal as the primary fuel.	A thermal efficiency of 32.18%, 80.10%, 38.73% and 50.33% was achieved when the stove was fuelled with charcoal, sawdust, wood, and groundnut husk, respectively. The highest flame temperature was recorded as 205ºC when wood was used as fuel. The highest stove body temperature recorded was 56ºC.	(Odesola *et al.,* 2019)
Designing, Simulating, and Manufacturing of an Improved Charcoal Stove	Thus, this study aims at designing, simulating, and manufacturing an improved charcoal stove to maximize the thermal	About the experimental investigation, the thermal efficiency of the stove is 32.6% and its specific fuel consumption is 56 g of fuel/ liter of water. The study showed an improvement in the thermal performance of the charcoal stove. The specific fuel consumption of the prototype charcoal stove shows 70% improvement compared to the three-stone fire. Generally, the new prototype charcoal stove has better thermal performance compared to the previous designs proposed by other researchers.	(Lemma, 2020)
Efficiency and emissions of charcoal use in the improved Mbaula cookstove	An improved chamber method was used to evaluate the thermal performance and emission characteristics of charcoal in an unvented cookstove known as the Improved Mbaula.	Emissions of CO were 340 g/kg charcoal at full air input, which was taken to be the normal mode of operation. The average thermal efficiency (PHU) of the improved mbaula was 25% compared to 29% for the traditional charcoal stove.	(Kaoma *et al.,* 1994)
Performance Evaluation of Waste Heat Recovery in a Charcoal Stove using a Thermo-Electric Module	In order to improve the efficiency of charcoal stoves, various researchers have tried integrating a thermoelectric module into the charcoal stove.	The thermoelectric charcoal stove generated a maximum voltage of 5.25V at an ambient temperature of 29ºC. The least maximum voltage was generated at the highest ambient temperature of 36ºC. It was observed that the maximum voltage increased with decreasing ambient temperature; this could be attributed to the ambient air being used to cool the thermoelectric generator. Therefore, it could be said that the performance of a forced-draft thermoelectric charcoal stove increases with a decrease in ambient temperature.	(Dobie & Sharma, 2018)
Assessment of pollutant emissions and energy efficiency of four commercialized charcoal stoves with the modified Chinese cooking stove protocol	This research evaluated four commercialized charcoal stoves with a clay baseline stove using a modified Chinese cooking stove protocol that considered the local cooking habit to make the testing results more useful for the local stove promotion.	The results showed that the thermal efficiency of the tested charcoal stoves ranged from 38.7% to 47.5%, and the cooking power was around 640-1200 W. The CO emission factors of the improved stove had a 60% reduction compared with the baseline stove. Different indicators reporting the same aspect of the stove were evaluated, and it was suggested to choose the indicators according to the project requirements.	(Zhang *et al.,* 2018)
The Assessment of Combustion	To conduct efficiency and charcoal-saving analyses, a set	When Abura charcoal and other types of charcoal (assorted) were tested to	(Vandy, 2023)

Performance of Improved Cookstoves in Sierra Leone	of charcoals from the Abura tree (Mitragyna ciliata) and another set from assorted trees: Mango tree (Mangifera indica) and Matchstick tree (Aechmea gamosepala) were prepared.	determine the efficiency of the stoves, the results obtained for the Wonder stove showed average efficiencies of 19.67% and 14.68%, respectively, while those for the Metal stove showed efficiencies of 17.79% and 14.75%. When burned charcoals were compared at the high-power phase cold start in both stoves, the Wonder stove saved 54.21% of the charcoal with a corresponding time of 4.42 minutes, while the Metal stove saved 1.40% of the charcoal with a similar time of 4.34 minutes.	
Evaluation of a powered charcoal stove by using different biomass fuels	A powered stove was designed to utilize biomass effectively with easy ignition, uniform fire, and shorter cooking time.	The results also show that the specific fuel consumption decreased with air flow rate when yams, rice, and beans were cooked. On the other hand, the time spent cooking the items increased significantly ($P \leq 0.05$). Also in comparison, the specific charcoal consumption for cooking yams, rice, and beans was less, followed by wood and corncobs. The results show that when powered, the stove performed much better than under natural air flow conditions, and its efficiency increased with an increase in volumetric air flow rate.	(Alakali *et al.*, 2011)
Development and performance analysis of top lit updraft: natural draft gasifier stoves with various feed stocks	The performance of an Ethiopian-designed and built-in gasifier stove was studied and evaluated.	The efficiency of this stove was calculated utilizing those three feedstocks. As a result, the gasifier stove's efficiency, having eucalyptus, sawdust-cow dung briquettes, and bamboo as feedstock, was 32.30 ± 0.3%, 31.5 ± 0.5%, and 26.25 ± 0.25%, respectively. This proportion did not include the ultimate charcoal production, but when this yield was employed as an energy input for additional charcoal burners, it increased to 53 ± 2%. When compared to local stoves and foreign gasifier stoves, whose efficiency is in the range of 10 %–39% this efficiency rating was exceptional because the space between the internal and external cylinders helps the secondary air to preheat before combustion, and also the interior hollow cylinder helps the primary air to move evenly in a vertical circular pattern for proper gasification.	(Hailu, 2022)
A Study of the Thermal Efficiency of a Double-Air Inlet Door Charcoal Stove	The objectives of this research were to study the effects on thermal efficiency of the amount of air entering through the double-air inlet doors charcoal stove.	The test results indicated that the thermal efficiency of the third trial increased to 42.75 %, higher than the first trial (19.50 %). The condition to slow down the exhaust gas by the pot cover in the last trial gave the highest efficiency value of 50.75 % and the combustion temperature was higher; also, the specific fuel consumption was decreased.	(ธีระเจตกูล *et al.*, 2019)
Comparison of the Performance of Biomass Briquette Stoves on	The performance analysis of the biomass briquette stove has been carried out.	The results showed that the maximum fire temperature of clay, steel, and aluminum stoves was obtained, respectively, 798°C, 617°C, 508°C, and thermal efficiency of	(Djafar *et al.*, 2021)

Three Types of Stove Wall Materials		73.66% for clay, followed by a steel stove of 38.98% and the lowest is obtained on an aluminum-based stove, which is only 11.49%.	
Design and Techno-economic Analysis of an Improved Multipurpose Cooker Stove	This research aims to design and assess the performance of an improved multipurpose cooker stove.	The improved multipurpose cooker stove demonstrated a thermal efficiency of 87.49%, significantly higher than the 11.88% thermal efficiency of traditional stoves. This improvement in efficiency is crucial for reducing fuel consumption and maximizing heat transfer during cooking processes. In addition, the research findings showed that the improved multipurpose cooker stove consumed 0.3643 kg/L less fuel compared to traditional stoves. This fuel savings not only reduces the cost of raw materials but also contributes to environmental sustainability by lowering deforestation rates and air pollution.	(Kaputo & Mwanza, 2024)

4. DISCUSSION

The assessment of innovations in charcoal stove technology has persistently highlighted quantifiable advancements in thermal efficiency, diminished emissions, and enhanced combustion efficacy when juxtaposed with conventional stoves. Olaoye *et al.*, (2018) indicated that an optimized vented charcoal stove attained a combustion rate of 0.0129 kg/min, surpassing the traditional stove's combustion rate of 0.0155 kg/min. Despite the relatively small difference in thermal efficiency between the two stove designs (17.61% for the upgraded model and 16.41% for the native version), the upgraded stove had significantly higher combustion efficiency and lower carbon monoxide (CO) emissions to levels that were EPA-acceptable. This finding suggests that even minor design modifications can produce significant health and environmental advantages. Wider environmental ramifications were underscored by Obeng *et al.*, (2017), who investigated the operational effectiveness of three biomass cookstoves in Ghana. Their research revealed that the Gyapa charcoal stove mitigated global warming effects by 75% in comparison to wood-burning stoves, and by 50% relative to coalpot stoves. This performance indicates that charcoal stoves, when reengineered for enhanced efficiency, not only conserve fuel but also substantially decrease greenhouse gas emissions. These results are congruent with international objectives aimed at alleviating climate impacts through cleaner domestic energy solutions.

Further investigation by Atajafari *et al.*, (2024) emphasized the necessity of integrating theoretical modeling with experimental verification. Their analysis of a single-mouth enhanced stove documented a practical thermal efficiency of 27%, which is marginally lower than the theoretical value of 31.45%. This discrepancy underscores the critical need to consider combustion losses and actual user behaviors when assessing stove performance. In a similar vein, Olarotimi *et al.*, (2025) evaluated an environmentally sustainable charcoal stove utilizing the Water Boiling Test, reporting an efficiency of 26.4%. While this figure is modest in relation to cutting-edge prototypes, it corroborates that practical design enhancements can consistently exceed baseline stoves in both efficiency and economic viability. Innovative design methodologies also present superior performance metrics. Lemma (2020) illustrated that optimized stoves, equipped with enhanced combustion chambers, attained efficiencies of 32.6%, alongside a 70% reduction in specific fuel consumption in comparison to traditional three-stone fires. Zhang *et al.*, (2018) further documented efficiency levels varying from 38.7% to 47.5% for four commercialized stove models, coupled with a 60% decrease in carbon monoxide emissions relative to clay stove baselines. These findings indicate that deliberate design enhancements concerning airflow and insulation substantially enhance energy transfer while concurrently mitigating deleterious emissions. Superior efficiency standards have been identified in sophisticated designs such as gasifiers and multipurpose stoves. Odesola *et al.*, (2019) reported a thermal efficiency of 32.18% for a charcoal-based multi-fuel gasifier, whereas efficiencies utilizing alternative fuels such as sawdust attained 80.10%. In a similar vein, Kaputo and Mwanza (2024) engineered a multipurpose cooker stove that achieved an efficiency of 87.49%, markedly exceeding the 11.88% efficiency recorded for traditional stove designs. These investigations underscore the transformative potential of advanced engineering designs in redefining household energy consumption by significantly reducing charcoal utilization while enhancing cooking duration and emissions performance. Nonetheless, performance inconsistencies persist. Kaoma *et al.*, (1994) discovered that the Improved Mbaula stove realized a 25% efficiency, which was inferior to the 29% efficiency noted for traditional stoves in their analysis. Djafar *et al.*,

(2021) also demonstrated that material selection markedly influences performance outcomes, with clay stoves achieving an efficiency of 73.66% in contrast to merely 11.49% for aluminum-based alternatives. These findings elucidate that performance superiority is not uniformly applicable across all enhanced designs and that material composition, local contexts, and user practices significantly impact the results.

Collectively, the studies examined and summarized in Table 1 indicate that while efficiency improvements vary from modest enhancements to remarkable gains exceeding 80%, the overall trend is predominantly favorable. Innovations in combustion chamber architecture, insulation, airflow optimization, and multifunctionality have collectively advanced the performance of charcoal stoves. However, a critical analysis reveals that efficiencies reported in laboratory settings do not invariably correlate with household performance outcomes, thereby indicating a necessity for further field-based validation to ensure sustainable adoption.

5. CONCLUSION

The examination of innovations in charcoal stove technology indicates that enhanced designs consistently surpass conventional models regarding thermal efficiency, combustion quality, and emissions management. Documented efficiencies have been observed to range from modest enhancements of approximately 17–27% in slightly redesigned stoves (Olaoye *et al.*, 2018; Atajafari *et al.*, 2024) to substantial improvements exceeding 80% in sophisticated multipurpose cooking devices (Kaputo & Mwanza, 2024). These results affirm that technological advancements possess the potential to significantly diminish fuel consumption, mitigate harmful emissions, and enhance the efficiency of household cooking practices. Furthermore, innovations such as gasifier stoves and thermoelectric modules illustrate that efficiency enhancements may be integrated with multifunctionality, yielding both energy conservation and broader socio-economic advantages. Nevertheless, challenges remain evident. Certain investigations, including those by Kaoma et al. (1994), revealed that advanced stoves might exhibit suboptimal performance in comparison to traditional models under particular circumstances, while Djafar et al. (2021) highlighted the pivotal importance of material selection in realizing efficiency improvements.

Future studies should concentrate on user-centred design, durability testing, and field-based performance validation in light of these findings to guarantee long-term adoption (Iweka *et al.*, 2019; Okechukwu *et al.*, 2012; Okonkwo *et al.*, 2012; Eze *et al.*, 2021; Uzoechi *et al.*, 2025; S. O. N. K. Onyegirim *et al.*, 2025b). Policymakers should encourage access by providing financial aid or subsidies, and awareness-raising initiatives can help remove behavioural and cultural obstacles to adoption. To optimise benefits at the home and societal levels, hybrid and multifunctional features should be investigated. All things considered, advancements in charcoal burner performance offer a direct route to more sustainable, effective, and clean cooking options in areas where charcoal is used.

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