Improvisation of Nigeria Clay and Imported Insulated Fibre as Alternative for Down-Draft Kiln Construction

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Abstract: Nigerian ceramic and artisans face a significant obstacle, the high cost and unreliable electricity required to operate imported electric kilns. The study specifically examines the viability of designing and constructing an economical efficient down-draft kiln using a blend of locally sourced Nigerian clay from Ondo and imported insulated fibre as main construction materials with sole aimed to formulate a greater clay-fibre kiln wall with superior refractory and insulating properties, and to evaluate its performance against traditional firebrick kilns. The study adopted an experimental research design and is more than a technical exercise; it provides a practical and empowering blueprint for local artisans and entrepreneurs by offering a cost-effective alternative to expensive imports. This approach fosters technological self-reliance, reduces production costs, and stimulates sustainable growth within Nigeria's ceramics sector, demonstrating that unlocking industrial potential often lies not in foreign catalogues but in the innovative application of local materials and ingenuity. The study recommends that ceramic artists and institutions adopt this hybrid technique to promote sustainability and reduce production overheads, with further research encouraged on fibre-sourcing alternatives to enhance full localization.

Keywords: *Nigeria; Kiln Construction; Refractory Clay; Improvisation; Ceramic Fibre; Local Fabrication; Down-Draft Kiln; Appropriate Technology; Small-Scale Industry.*

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I. INTRODUCTION

The quest for thermal efficiency and economic sustainability in ceramic production represents a fundamental challenge, particularly in developing nations like Nigeria where the ceramics industry is a vital, yet often under-resourced, sector. At the heart of this challenge lies the kiln the most critical and capital-intensive equipment in the ceramic value chain. For decades, the Nigerian pottery and ceramics sector has been constrained by a technological dilemma: the reliance on expensive, imported kiln technologies versus the inconsistent performance of traditional, all-clay kilns. This study addresses this predicament by investigating a novel, hybrid approach: the improvisation of a downdraft kiln using a composite lining of locally sourced Nigerian clay and imported insulating fibre. Idu, Oghale & Sarah, 2017).

The term "ceramic" describes non-metallic, inorganic materials that are usually heated to high temperatures to solidify them. Ceramics, which are derived from the Greek term keramos, which means "potter's clay," are a broad category of objects made from natural raw materials, mostly clay, that are sculpted while pliable and then fired to permanently harden them. Nigeria's manufacturing of ceramics is severely hampered by its reliance on foreign firing technology and unstable power supply. The majority of artists and small-scale businesses are still unable to afford foreign kilns, and frequent power outages make electric kilns unstable, which disrupts production and lowers quality. This combination restricts the sector's economic potential and stifles innovation. Akaolisa, Oparah & Agbasi, (2022). The downdraft kiln design, renowned for its superior temperature uniformity and control, remains an industry standard for achieving high-quality ceramic wares. However, its construction in Nigeria has historically been hampered by material challenges. Traditional kilns built entirely from local refractory clays, while economically accessible, often suffer from high thermal mass and significant heat loss, leading to excessive fuel consumption and prolonged firing cycles.

Conversely, modern kilns lined with high-performance insulating fibre offer exceptional energy efficiency due to their low thermal conductivity and low thermal mass. Yet, for the average Nigerian artisan or small-scale industrialist, these materials are prohibitively expensive and dependent on foreign exchange, creating a significant barrier to technological advancement Ashioba & Udom, (2023).

The concept of appropriate technology is especially essential in this context, emphasizing solutions that are local-specific, accessible to small-scale operators, and sustainable within existing technical and economic frameworks (Adeyemi, 2021). Kiln construction in Nigeria has traditionally relied on imported refractory materials, but new research into indigenous refractory clay deposits has identified intriguing alternatives that may minimize this reliance (Mbakaan & Iferi, 2020). Furthermore, the use of ceramic fiber, even if initially imported, provides insulating benefits that can be paired with locally made components to obtain ideal thermal performance.

This study addresses these issues by creating a practical, indigenous answer through improvisation with existing resources. The project's goal is to design and build a functional down-draft gas kiln with two burner ports using locally sourced refractory clay and imported ceramic fiber for crucial parts. The study discovers relevant local materials, develops appropriate technological designs, and evaluates kiln performance in terms of temperature capacity, thermal efficiency, firing uniformity, and economic viability for small-scale firms. The relevance resides in the provision of a design for cost-effective, energy-secure kilns that reduce import dependence while also empowering Nigerian ceramists through technical self-reliance. By proving that down-draft kilns can be made locally using indigenous materials, this study helps to establish appropriate technical solutions that boost Nigeria's small-scale industrial sector while preserving ceramic traditions Oyedoh, Okwah & Oshomogho, (2023).

Despite the clear potential of both material classes, a significant research gap exists. While studies have optimized the properties of Nigerian clays and explored composite refractories, there is a lack of published work on the practical integration of these local clays with modern insulating materials in a functional kiln structure. The central problem this study addresses is the absence of empirical data on the performance, durability, and economic viability of a hybrid downdraft kiln that uses abundant Nigerian clay as a structural hot-face and strategically placed imported fibre as a high-efficiency backup insulation layer Mokwa, Lawal, Abolarin & Bala, (2019).

By building upon recent advances in the characterization of Nigerian clays and the established principles of energy-efficient kiln design, this research seeks to develop an "outstanding" alternative a kiln that is not only affordable and built from local resources but also embodies the operational efficiency of modern technology. The outcome promises to democratize access to efficient firing technology, fostering a more sustainable and competitive ceramics industry in Nigeria.

II. LITERATURE REVIEW

➢ *Kiln Firing Technology, History and Principles*

Kiln technology has evolved dramatically since pit firings first appeared around 6000 BC. Bachtiar, Ibrahim and Abdullah (2019) explain that moving from bonfire techniques to sophisticated kiln structures enabled higher temperatures and better control over ceramic processes. Garraty (2011) notes pottery's significance as humanity's first synthetic material, with experimental firings dating back 30,000 years. According to Adegbuyi, Adeyemi and Ogunleye (1970), the ceramic industry truly emerged when societies discovered clay could be permanently hardened through heating.

In Nigeria, traditional firing methods show remarkable ingenuity, though the Department of Fine Arts and Design, University of Port Harcourt and Umoh (2021) report that indigenous kilns typically reached only 800-900°C insufficient for vitrified stoneware. This limitation remains a critical constraint that modern designs must overcome while adapting to locally available materials (Rhodes, 2018).

➢ *Down-Draft Kiln Design Principles*

Down-draft kilns optimize heat transfer by manipulating airflow through critical components: the combustion chamber, bag wall directing gases upward, and flue system creating necessary draft (Guidance Document for Fuel Burning Equipment, n.d.). Govind, Sharma and Kumar (2021) emphasize that successful construction requires precise calculation of chamber proportions relative to flue size and burner capacity. The thermodynamic principal forces hot gases to travel a longer path through ware, creating more uniform temperature gradients than updraft designs (Rhodes, 2018). Dual-burner configurations offer superior temperature control and operational redundancy compared to single-burner designs.

➢ *Gas Kilns and Nigerian Context*

Gas kilns offer distinct advantages where electrical infrastructure is unreliable. Their controlled combustion enables precise temperature and atmosphere regulation, allowing glaze effects impossible in electric kilns (Govind, Sharma and Kumar, 2021). Independence from grid electricity makes gas kilns practical for Nigerian small-scale industries facing frequent power outages.

Ali (2008) documented that previous gas kiln installations in Nigeria achieved functionality but faced challenges: limited temperature range below 1150°C, uneven heat distribution, and short refractory lifespan due to thermal stress. These limitations highlight the importance of careful design and material selection for professional ceramic production.

➢ *Refractory Materials and Indigenous Alternatives*

Refractory materials require high refractoriness, low thermal conductivity, and good thermal shock resistance (Oladipo, Adeyemi and Mohammed, 2019). Nigerian clay

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deposits show promising characteristics: Mbakaan and Iferi (2020) found Kwoi fireclay with pyrometric cone values of 32-34, suitable for stoneware firing up to 1300°C. Eze-Uzomaka (2009) identified Niger Delta clays with alumina exceeding 25%, accessible to local potters.

Indigenous refractory development has advanced significantly. Oladipo, Adeyemi and Mohammed (2019) successfully produced standardized refractory bricks from Nigerian clays, proving locally fabricated products meet technical standards at lower cost. Adeyemi (2018) investigated rice husk ash as insulating material, demonstrating adequate thermal resistance at substantially lower cost than imported ceramic fibre.

- *Improvisation and Local Fabrication Techniques*

Improvisation in kiln construction involves adapting available materials to achieve functional equivalents of imported technologies. Filani (1999) demonstrated that Ahmadu Bello University projects achieved stoneware temperatures with proper guidance, though reliance on combined local and imported materials initially hindered reproducibility. Eze-Uzomaka (2009) showed collaborative construction reduces costs while building technical capacity among participants. Local fabrication extends to burner systems, flue controls, and kiln furniture. Nnaji (2015) emphasizes that successful fabrication requires understanding combustion dynamics, not merely mechanical assembly. Ali (2012) proved simple modifications optimize standard burner designs for locally available propane, improving combustion efficiency.

- *Burner Systems and Combustion Efficiency*

Atmospheric venturi burners mix air and fuel without mechanical assistance, suiting small-scale operations where simplicity matters. Rhodes (2018) indicates properly designed venturi burners achieve over 85% combustion efficiency. Stoichiometric balance determines completeness; insufficient air creates reduction atmospheres while excess air wastes heat (Nnaji, 2015). Dual-burner configurations provide operational redundancy, allowing one burner to maintain temperature if the other fails (Govind, Sharma and Kumar, 2021). Burner placement relative to the bag wall and flue system critically influences heat distribution.

- *Ceramic Fibre Applications*

Ceramic fibre, though imported, provides exceptional thermal performance when strategically incorporated into locally fabricated kilns. Its low thermal mass and high insulating value reduce heat loss, improving fuel efficiency and enabling faster firing cycles (Oladipo, Adeyemi and Mohammed, 2019). Dense refractory brick combined with fibre backup insulation creates composite wall systems optimizing both structural integrity and thermal efficiency. Due to high import costs, fibre should be strategically applied where most beneficial. Adeyemi (2021) suggests fibre linings in kiln doors and roofs with minimal structural loads offer most cost-effective use. Local fabrication of dense bricks with selective fibre application balances performance with economic constraints.

- *Indigenous Refractory Development*

Developing indigenous refractory materials advances technological self-reliance while creating opportunities for local capacity building. Recent research has formulated compositions from Nigerian fireclay, kaolin, and agricultural waste achieving properties comparable to imports (Adeyemi, 2021). These innovations reduce costs and generate local employment. Mbakaan & Iferi (2020) established baseline data for Nigerian refractory clays, including pyrometric cone values and thermal shock resistance. This scientific foundation enables informed selection of clay deposits for specific kiln applications.

- *Ceramic Firing Quality*

Ceramic firing transforms clay bodies and glazes, ultimately determining product quality and market value. Inconsistent firing conditions cause significant losses through cracking, bloating, or glaze defects (Eze, 2019). Reliable firing technology is fundamental for advancing product quality and competitiveness, particularly for small enterprises with limited capital. Temperature uniformity directly affects production consistency. Down-draft designs promote more even heat distribution than updraft configurations, reducing temperature differentials that cause variation in glaze maturation (Rhodes, 2018). This uniformity translates to reduced waste and improved product quality.

- *Small-Scale Industry Context*

Small ceramic enterprises contribute vitally to employment and economic diversification but face capital constraints limiting technology acquisition (Adeyemi, 2021). Affordable, efficient firing technology directly influences production capacity, quality, and viability, making kiln development a priority for sector support. Appropriate technology emphasizes solutions that are affordable and maintainable with local skills. Nnaji (2021) notes initial kiln investment significantly influences long-term production economics, with locally fabricated kilns offering advantages in both cost and maintenance accessibility.

- *Kiln Fabrication Considerations*

Successful kiln fabrication requires careful consideration of thermal expansion, structural loads, heat transfer, and combustion dynamics (Rhodes, 2018). Thermal expansion joints accommodate dimensional changes during heating and cooling, preventing stress cracks. Structural support systems must carry refractory weight at operating temperatures. Localized fabrication creates opportunities for skills development beyond immediate projects. Eze (2019) observed artisans gain transferable skills applicable to foundries, bakeries, and other thermal processing industries.

- *Cost-Effective Production*

Initial kiln investment significantly influences long-term production economics, particularly where capital is scarce (Nnaji, 2021). Kilns from indigenous materials offer substantial advantages in initial cost while providing accessible maintenance. The economic case strengthens considering foreign exchange constraints. Operating costs, particularly fuel consumption, influence long-term viability. Properly designed down-draft kilns achieve thermal

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efficiencies superior to traditional methods, reducing fuel requirements (Govind, Sharma and Kumar, 2021).

- *Local Entrepreneurship*

Affordable kiln technology empowers entrepreneurs by reducing barriers to entry (Eze, 2019). When aspiring ceramists can access firing technology at reasonable cost, more individuals establish studios, increasing sectoral output. Knowledge spillovers from localized fabrication can stimulate complementary businesses. Adeyemi (2021) emphasizes technology development must proceed alongside business skills training. Entrepreneurs need understanding of firing economics, production planning, and market development.

- *Previous Kiln Construction in Nigeria*

Ali (2008) documented local kiln constructions achieving functional status but facing recurring challenges: limited temperature range below 1150°C, uneven heat distribution, and short refractory lifespan. These experiences inform current design improvements. Filani (1999) demonstrated Ahmadu Bello University projects achieved stoneware temperatures, though reliance on combined local and imported materials reduced reproducibility. Oladipo, Adeyemi and Mohammed (2019) subsequently developed standardized refractory bricks from Nigerian clays. Eze-Uzomaka (2009) showed collaborative construction reduces costs while building technical capacity. This accumulated experience provides valuable guidance for current efforts. This research builds upon prior work while incorporating improved materials understanding and design refinements to achieve reliable stoneware firing with predominantly local resources.

Fig 1,2,3,4; Wooden Mould, Casting Process and Firing of the Bricks

III. CONSTRUCTION PROCEDURE

The down-draft kiln was constructed following a precise, sequential procedure to ensure structural integrity and functional efficiency.

- *Foundation*

Construction began with establishing a solid foundation: a reinforced concrete slab measuring 1600 mm long, 1600 mm wide, and 120 mm thick (approximately 4 ft x 4 ft x 4 in). This slab was reinforced with wire mesh to prevent cracking and provided a level, stable platform, isolated the kiln from ground moisture, and created a non-combustible base for safety (Norton, 1973).

- *Structural and Burner System Materials*

Frame and Casing: The frame was constructed from mild steel angle iron (50mm x 50mm x 5mm). The outer casing was made of 3mm mild steel sheets. All steel was sourced from local metal fabricators.

Burner Ports and Gas System: Two 1.5-inch diameter, schedule 40 steel pipes were fabricated to serve as burner ports. The gas system included standard LPG cylinders, high-pressure hoses, regulators, and two needle valves that allowed for independent burner control.

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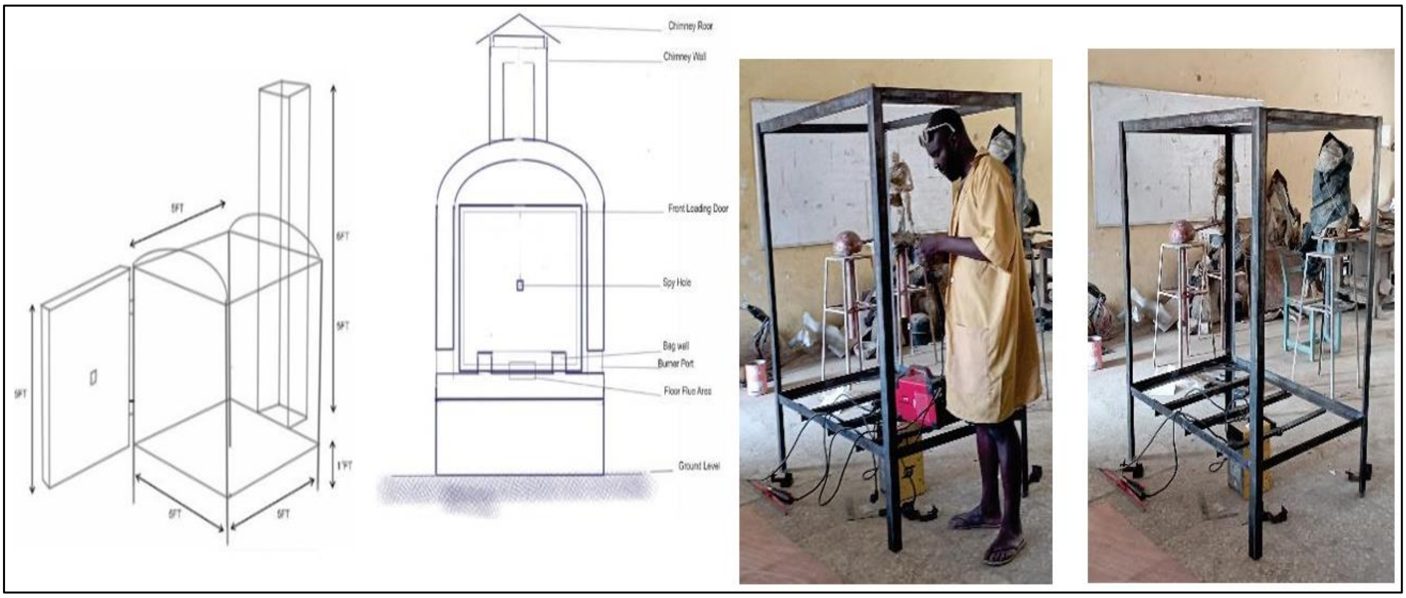

Fig 5, 6, 7 and 8; Sketches and Construction of the Structural System

➢ *Base and Floor:*

After curing the concrete foundation, the kiln chamber's internal floor was constructed using fabricated refractory bricks laid with a thin layer of refractory mortar. A critical technical aspect was the incorporation of a slight slope (approximately 1.5 to 2 degrees) across the entire floor, directed toward the flue opening. This slope was designed to channel condensation and any loose debris away from the ware during the initial firing stages and towards the flue for removal, thus protecting the pottery from damage (Rhodes, 1968).

➢ *Wall Construction:*

The kiln walls were built upwards, course by course, from the firebrick floor to a final height of 900mm (36 inches), creating the desired chamber volume. During wall construction, key internal components were integrated:

Fig 9 and 10; Wall Construction

- Combustion Chamber: A 200mm x 400mm (8in x 16in) area was created on one side to house the burners.

➢ *Bag Wall:*

This internal wall, approximately 450mm (18in) high, was positioned between the combustion chamber and the main ware chamber. Its purpose is to force the flames upwards toward the kiln's crown before being drawn down through the pottery. This airflow pattern is the defining characteristic of a downdraft kiln (Rhodes, 1968).

➢ *Arch Construction:*

A sprung arch was constructed to form the kiln's roof. A wooden form with a specific radius supported the bricks during construction. The refractory bricks for the arch were precisely cut into a trapezoidal shape and carefully laid over

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the form using refractory mortar. The arch was designed with a 150 mm (6 in) rise over its 1200 mm span. The wooden form remained in place for 48 hours to allow the mortar to develop sufficient strength before removal. This self-supporting arch design effectively transfers lateral forces outward to the steel frame (McDonald, 2023).

➢ *Chimney and Damper:*

The required chimney height for the downdraft kiln was determined using a proportional formula that considers both vertical and horizontal flue runs: height equals three times the downward pull plus one-third of the horizontal pull. With a horizontal flue run of 18 feet and a downward pull of 5 feet, the calculated chimney height was 21 feet:

$$(3\times5)+ \left(\frac{18}{3}\right) = 15 + 6 = 21ft$$

This calculated height was validated during performance testing, proving essential for generating a strong, consistent draft. Adequate draft is critical for efficient combustion, stable heat circulation, and uniform high-temperature firing throughout the chamber. Insufficient chimney height often results in poor airflow, incomplete combustion, and uneven temperature distribution (Smith, 2021; Kumar & Patel, 2020).

The validation of this calculated height demonstrates that proper chimney design directly influences kiln efficiency and firing quality. By achieving the recommended proportions, the downdraft kiln maintained reliable draft strength, contributing to its superior thermal performance and consistent results compared to traditional updraft designs (Chen, Wang & Zhang, 2022).

➢ *Burner Installation:*

Two burner ports, each 50 mm (2 in) in diameter, were installed into the combustion chamber wall at the designated openings. High-temperature ceramic fibre was used to seal any gaps around the burners. The burners were then connected to the LPG gas system using approved gas fittings and hoses, ensuring a secure, leak-free connection.

➢ *Installation of Imported Fibre*

Installing imported fiber begins with surface preparation. Ensure the surface is well-sealed and free of cracks by applying refractory mortar to create a firm base. Next, measure and cut fiber blankets or boards to fit the kiln walls, leaving slight overlaps to prevent gaps. Secure the fiber to the kiln wall using stainless steel pins or hooks, pressing the insulation firmly against the surface, starting from the bottom and working upwards. Secure each section tightly, overlapping them by 30 mm to minimize heat leakage. During testing, the kiln's exterior remains noticeably cooler, indicating the fiber insulation effectively retains heat inside. This results in improved energy efficiency, reduced fuel consumption, and more consistent firing conditions. The kiln becomes more reliable and economical, as the insulation acts as a barrier, concentrating heat within the interior where it is most needed.

Fig 11, 12 and 13, Installation of Imported Fibre

IV. FIRING EVALUATION

After the kiln had completely cooled, the internal structure was inspected for any cracks or spalling. The fired test pieces were evaluated for glaze maturity and body vitrification. The bending of the pyrometric cones confirmed the heat work achieved and the temperature uniformity throughout the chamber, providing a comprehensive assessment of the kiln's performance (Kingery, Bowen & Uhlmann, 2021). Finally, a systematic operational testing phase was conducted. The completed kiln underwent multiple controlled firing cycles. During these tests, operational data on maximum temperature attainment, heat distribution uniformity, and fuel consumption were meticulously collected and analyzed (Oladipo & Eze, 2022). This empirical data was used to evaluate the functional performance of the kiln and the effectiveness of the material improvisation.

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V. RESULT AND DISCUSSION

This reports how well a downdraft kiln built with Nigerian clay and lined with imported insulated fibre performs both thermally and operationally. The assessment was carried out through controlled firing tests using three different ceramic clay bodies, each taken to its own maturation temperature. The kiln showed a consistent and efficient heating pattern, with firing times increasing in line with the target temperatures. The low-fire earthenware body reached 900 °C in 6 hours, the mid-fire body achieved 1000 °C in 7 hours, and the high-fire stoneware body successfully matured at 1200 °C in 8 hours. These results highlight the kiln's stable heat retention and effective combustion management, as seen in its predictable ramp rates and controlled firing cycles. The quality of the fired pieces across all three tests was consistently excellent. Careful inspection of samples taken from different zones of the kiln chamber top, bottom, front, and back showed uniform vitrification, reliable maturity, and even colour development. This remarkable consistency throughout the load demonstrates that heat was distributed evenly, with minimal thermal variation. It highlights one of the key advantages of the downdraft design, further strengthened by the kiln's high-performance insulation.

A comparison with a traditional updraft brick kiln of similar volume highlights the superior efficiency of the downdraft design. Whereas the updraft kiln required more than 12 hours to reach 1000 °C and produced uneven results with some pieces under-fired, others properly fired, and some over-fired the fabricated downdraft kiln eliminated these inconsistencies entirely. From an operational standpoint, the kiln offers a practical production capacity well-suited to a studio or small workshop. It can hold around 200 average-sized ceramic pieces in a single firing cycle. Economically, the project is highly attractive: the total construction cost was just ₦4.200,000 representing a very low capital investment. When combined with its rapid, efficient firing cycles and consistently high-quality output, the kiln presents a compelling value proposition for individual artisans, educational institutions, and small-scale ceramic enterprises.

The downdraft kiln built from Nigerian clay and insulated with imported fibre has proven to be a highly effective design. It consistently reaches precise temperature targets while delivering superior firing uniformity and thermal efficiency compared to conventional low-cost kilns. The system is both technically robust and economically advantageous, offering reliable performance at a fraction of the typical investment.

VI. CONCLUSION

The downdraft kiln constructed from Nigerian clay and imported insulated fibre has proven to be an exceptional success in performance evaluation. It reliably achieves target temperatures 900°C, 1000°C, and 1200°C in efficient 8 to 12-hour cycles, with outstanding thermal uniformity and consistent, high-quality ceramic results. Its performance is significantly superior to traditional updraft kilns in terms of speed, consistency, and fuel efficiency. Therefore, the fabrication and adoption of this kiln design is highly recommended. Its low material cost and practical batch capacity make it an ideal and accessible technology for studio potters and small-scale ceramic producers vocational, technical, and educational institutions, community art programs and cultural heritage initiatives.

RECOMMENDATION

- To ensure optimal results, users should adhere to the established firing protocols.
- A longitudinal study to monitor the long-term durability of the local materials is recommended to secure the kiln's sustainable use.

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