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Evaluation of a Fit-for-Purpose Earthen Oven for Drying of Basic Household Consumables in Rural Areas

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Abstract

The increasing demand for efficient food preservation methods in rural areas has prompted the exploration of innovative drying technologies. Traditional drying methods often fall short in terms of efficiency and effectiveness, leading to significant food wastage and economic losses. This study evaluates the design, fabrication, and experimental testing of a fit-for-purpose earthen oven specifically tailored for drying basic household food consumables in rural settings. The problem statement centers on the inadequacy of existing drying methods, which are often energy-intensive, time-consuming, and reliant on favorable weather conditions, thereby limiting their utility in food preservation. The methodology employed in this study involved a systematic approach to the design and fabrication of the earthen oven, integrating local materials and traditional construction techniques to ensure accessibility and sustainability. The design process was informed by principles of thermodynamics and heat transfer, optimizing the oven's structure to enhance airflow and heat retention. Experimental testing was conducted to assess the oven's performance in drying various food items. Key performance indicators included mass of charcoal, initial temperature, final temperature and heating time. The results of the experimental values for the test conducted for 10, 15, 20, 25 and 30 minutes at 2m/s, 3m/s and 4m/s airflow rate testing delivered minimum values of 200^0C at the initial temperature range and a maximum value of 300^0C as the final temperature ranges which demonstrated that the earthen oven significantly improved drying efficiency. Furthermore, the use of locally sourced materials not only reduced the overall cost of the oven but also fostered community engagement and ownership of the technology. The findings underscore the potential of the earthen oven as a viable solution for food preservation in rural areas, addressing both economic and nutritional challenges faced by households.

Keywords: Earthen oven, Fit-for-purpose, Drying, Household consumables.

1 | Introduction

Earthen ovens with automatic temperature control have gained significant attention in recent years due to their potential to improve drying efficiency and reduce energy consumption [1]. One of the essential features

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of an earthen ovens with automatic temperature control is their ability to maintain a consistent drying temperature, which is essential for achieving optimal drying results. Traditional earthen ovens often require constant monitoring and adjustment of the fire to maintain the desired temperature, leading to inconsistent drying outcomes. By incorporating automatic temperature control mechanisms, such as thermocouples and PID controllers, these ovens can maintain a steady temperature throughout the drying process, resulting in more evenly cooked food [2].

Several studies have demonstrated the effectiveness of automatic temperature control in earthen ovens. For example, incorporating a PID controller in an earthen oven resulted in a more stable drying temperature and improved drying efficiency compared to traditional ovens. Similarly, automatic temperature control systems can significantly reduce energy consumption and drying time, making earthen ovens a more sustainable drying option. In addition to improving drying efficiency, earthen ovens with automatic temperature control also have the potential to enhance food safety. Maintaining a consistent drying temperature is crucial for ensuring that food is cooked thoroughly and free from harmful bacteria. By eliminating temperature fluctuations, automatic temperature control systems can help prevent undercooked food and reduce the risk of foodborne illnesses [3], [4]. Despite the numerous benefits of earthen ovens with automatic temperature control, there are some challenges that need to be addressed. One of the main challenges is the cost of implementing these systems, which can be prohibitive for low-income households.

Additionally, there is a lack of standardized designs and guidelines for building earthen ovens with automatic temperature control, making it difficult for individuals to replicate these systems in their own homes. The literature on the design and production of earthen ovens with automatic temperature control highlights the potential of these systems to improve drying efficiency, reduce energy consumption, and enhance food safety [5]. While there are still challenges to overcome, further research and development in this area could lead to widespread adoption of these innovative drying technologies. An oven is a confined space intended for heating, baking, or drying purposes. Throughout history, many oven types have been utilised for drying purposes. Certain high-temperature ovens, referred to as kilns, are utilised for the production of ceramic items. Industrial ovens serve multiple purposes, such as chemical processing, food preparation, and electronics manufacturing [6]. An oven necessitates a regulated heat source and a chamber for food dehydration [7]. Humans have utilised ovens for food preparation for tens of thousands of years, predating written history and agriculture, indicating that ovens, especially outdoor varieties, have been integral to human civilisation development across the globe. Consequently, outdoor ovens of many shapes and designs are prevalent in numerous global culinary traditions today.

1.1 | Evolution of an Earthen Oven with Automatic Temperature Control

The history and historical evolution of the earthen oven can be traced back to ancient civilizations, where it played a crucial role in drying and food preparation. Earthen ovens, also known as clay ovens or mud ovens, have been used by various cultures around the world for centuries. These ovens are typically made from clay, mud, or other natural materials and are used to bake bread, roast meat, and cook a variety of dishes [8]. The use of earthen ovens dates back to ancient times, with evidence of their existence found in archaeological sites around the world. These early ovens were simple structures made from clay or mud, with a fire built inside to heat the drying chamber.

a.

b.

Fig. 1. Tripod earthenware cooking pots; a. Chinese tripod pottery food vessel with striated and impressed decoration and three flanges emulating bronze vessel shapes, b. German tripod cooking vessel, so-called grapen, fired under oxidizing atmosphere and coated with an engobe [9].

One of the earliest known examples of earthen ovens can be found in ancient Mesopotamia, where they were used by the Sumerians and Babylonians as early as 3000 BC. These early ovens were simple structures made from clay or mud bricks, with a fire pit at the bottom and a domed roof to trap heat. The heat from the fire would radiate throughout the oven, allowing for even cooking, drying and baking. Over time, the design and construction of earthen ovens evolved, with different cultures adding their own unique features and techniques. In ancient Greece, for example, earthen ovens were often built into the ground, with a domed roof made from clay or stone [10]. The Romans also made extensive use of earthen ovens, incorporating them into their homes and public buildings.

In the middle ages, earthen ovens became more sophisticated, with the addition of chimneys to improve ventilation and flues to control the temperature and airflow. These ovens were often built into the walls of castles and manor houses, and were used to bake bread and other foods for large households. In more recent times, the traditional earthen oven has been replaced by modern gas and electric ovens in many parts of the world. However, there has been a resurgence of interest in traditional drying methods and sustainable living, leading to a renewed interest in earthen ovens [11].

Today, earthen ovens can be found in communities around the world, from rural villages to urban homesteads. These ovens are often built by hand using locally sourced materials, and are used to cook traditional dishes and bake artisanal breads. One of the key developments in the history of earthen ovens was the introduction of automatic temperature control mechanisms. This innovation allowed cooks to regulate the heat inside the oven more precisely, resulting in more consistent drying results. Early automatic temperature control systems were often rudimentary, relying on simple mechanisms such as dampers or vents to adjust airflow and temperature [12]. However, as technology advanced, more sophisticated control systems were developed, including thermocouple and timers that could automatically adjust the heat as needed.

1.2 | Advancements in Earthen Oven with Automatic Temperature Control

Modern advancements in earthen ovens with automatic temperature control have revolutionized the way we cook and bake. These innovative ovens have come a long way, with the following advancements marking their evolution into efficient and user-friendly appliances. Some of the advancements in the evolution of earthen ovens with automatic temperature control are as follows:

I. The invention of the thermocouple: This device, which regulates the temperature inside the oven, was a game-changer for bakers and chefs alike. With the ability to set and maintain a specific temperature, drying of food items became more precise and consistent [13].

II. The integration of digital technology: This allows for even greater control over the drying process, with programmable settings and timers ensuring perfect results every time. The introduction of touch-screen interfaces further simplified the user experience, making it easier than ever to cook with precision [14].

III. The incorporation of smart technology: These ovens can now be controlled remotely via smartphone apps, allowing users to monitor and adjust the drying process from anywhere. This level of convenience and flexibility has made drying more accessible and enjoyable for people of all skill levels [15].

IV. The use of sensors and thermocouple to monitor and regulate the temperature inside the oven: These sensors can be placed at various points throughout the oven to ensure that the heat is distributed evenly and that the food is cooked at the desired temperature [16]. Additionally, some modern earthen ovens are equipped with digital displays that allow users to easily set and adjust the temperature, making it easier to achieve consistent results.

1.3 | Factors Affecting the Widespread Adoption of an Earthen Oven with Automatic Temperature Controller

Despite the potential benefits of an earthen oven with automatic temperature controller, the following factors may impact its widespread adoption.

I. Cost: One of the primary factors affecting the adoption of an earthen oven with an automatic temperature controller is the cost of the device. While traditional earthen ovens can be constructed using inexpensive materials, the addition of an automatic temperature controller can significantly increase the overall cost. This may make the technology inaccessible to individuals or communities with limited financial resources.

II. Cultural preferences: Another factor that may impact the adoption of this technology is cultural preferences. In many communities where earthen ovens are commonly used, there may be a strong attachment to traditional drying methods [17]. The introduction of a modern device like an automatic temperature controller may be met with resistance or skepticism. Additionally, some individuals may view the use of technology in drying as a departure from traditional practices.

III. Technical expertise: The successful adoption of an earthen oven with an automatic temperature controller also depends on the technical expertise of the users. While the device is designed to be user-friendly, individuals may still require some level of training or support to effectively operate and maintain the technology. Lack of technical knowledge or experience could hinder the widespread adoption of this innovation [18].

IV. Environmental considerations: Environmental factors may also play a role in the adoption of an earthen oven with an automatic temperature controller. While traditional earthen ovens are typically considered environmentally friendly due to their use of natural materials and renewable fuel sources, the addition of electronic components in the automatic temperature controller may raise concerns about energy consumption and electronic waste. Individuals or communities with a strong emphasis on sustainability may be hesitant to adopt this technology [19].

The widespread adoption of this technology is influenced by the aforementioned factors. While this technology has the potential to improve drying efficiency and consistency, these factors must be carefully considered in order to ensure successful implementation. By addressing these challenges and promoting the benefits of the technology, it is possible to increase the adoption of this technology in diverse communities.

1.4 | Types of Earthen Oven

Earthen oven comes in many forms, each with distinctive features differentiates it from the other. The different types of earthen oven commonly used are as follows:

I. Cob oven is made from a mixture of clay, sand, and straw (*Fig. 2*). To build a cob oven, a base is first constructed using bricks or stones, and then a dome-shaped structure is built on top using the cob mixture. The oven is then left to dry and harden before being fired up for both cooking and drying food items. Cob ovens are known for their excellent heat retention and even drying temperatures, making them ideal for baking bread, pizzas, and other dishes.

Fig. 2. Traditionally made cob oven [20].

II. Adobe oven is made from sun-dried bricks of clay and straw (*Fig. 3*). To build an adobe oven, the bricks are stacked in a dome shape and then covered with a layer of clay to seal in the heat. Adobe ovens are popular in Southwestern United States and Latin America, where they are used to cook traditional dishes such as tamales and empanadas.

Fig. 3. Traditional adobe baked oven [21].

III. Beehive oven is shaped like a beehive and made from layers of clay and sand (as shown in *Fig. 4*). To build a beehive oven, a wooden frame is first constructed in the shape of a dome, and then layers of clay and sand are applied to the frame to create the oven walls. Beehive ovens are known for their efficient use of heat and are commonly used in Mediterranean countries for baking bread and roasting meats.

Fig. 4. Beehive oven [22].

IV. Electric earthen oven (*Fig. 5*) uses electricity to power the temperature controller and maintain a consistent drying temperature. This type of oven is popular for its convenience and ease of use, as it eliminates the need for constant monitoring and adjustment of the temperature.

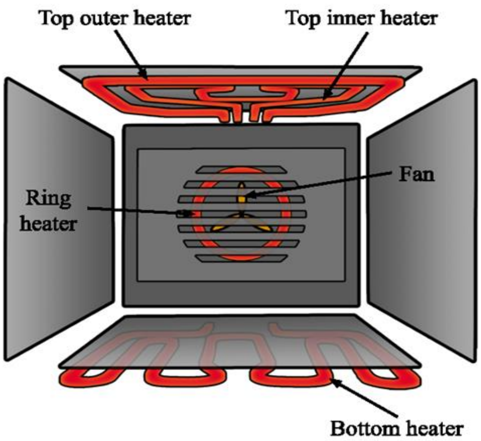


Fig. 5. Schematic diagram of an electric baking oven [23].

V. Gas-powered earthen oven uses natural gas or propane to heat the oven and regulate the temperature. This type of oven is often preferred for its efficiency and cost-effectiveness, as gas is typically cheaper than electricity. Additionally, gas-powered ovens (as shown in *Fig. 6*) are known for their ability to reach higher temperatures than electric ovens, making them ideal for drying certain types of food.

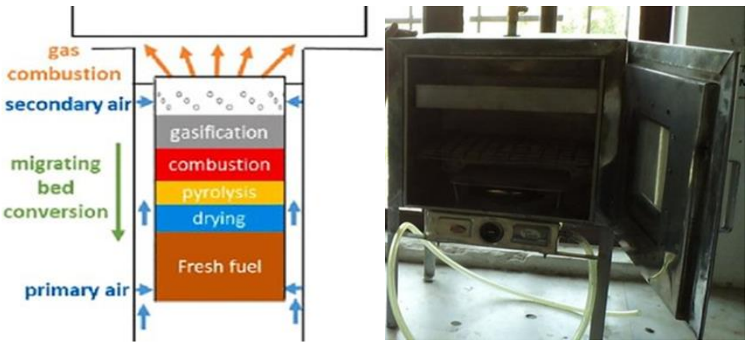


Fig. 6. Gas-powered earthen oven [24], [25].

Earthen ovens come in various types, each with its own unique construction and drying capabilities. Whether you prefer the simplicity of a cob oven, the durability of an adobe oven, or the efficiency of a beehive oven, there is a type of earthen oven to suit your drying needs.

1.5 | Applications of Earthen Oven

While earthen ovens are often associated with baking bread or pizza, their uses extend far beyond just drying. The various applications and uses of earthen ovens are as follows:

I. One of the primary uses of earthen ovens is for drying food. The design of these ovens allows for even heat distribution, resulting in perfectly cooked dishes. From baking bread and pizzas to roasting meats and vegetables, earthen ovens are versatile drying tools that can handle a wide range of culinary tasks. The high temperatures achieved in these ovens also makes them ideal for baking traditional dishes such as tandoori chicken or wood-fired pizzas [26].

II. Earthen ovens are also used for preserving food. The low humidity and consistent temperatures inside the oven create an ideal environment for drying fruits, vegetables, and herbs. This method of food preservation has been used for centuries in cultures around the world and is still practiced today in many communities [27], [28].

III. Another application of earthen ovens is for heating and warming spaces. In colder climates, earthen ovens can be used to heat homes, greenhouses, or outdoor spaces. The radiant heat produced by these ovens can provide a cozy and comfortable environment, making them a sustainable and cost-effective heating option [29].

IV. Earthen ovens are also used for traditional ceremonies and rituals. In many cultures, the act of drying or baking in an earthen oven is seen as a sacred and communal activity. These ovens are often used for special occasions such as weddings, festivals, or religious ceremonies, bringing people together to share food and celebrate [30].

Earthen ovens have a wide range of applications and uses beyond just drying. From preserving food to heating spaces and participating in cultural traditions, these traditional ovens play a significant role in many communities around the world. Their sustainable design, versatility, and cultural significance make them valuable tools that continue to be used and appreciated today.

1.6 | Drying Devices

The application of heat in processing materials, agricultural or non-agricultural, has seen the exploration of different technologies to achieving the aim of moisture reduction. The choice of drying (or heating) method could depend on properties such as; the expected drying range, the drying quality, the amount of material to be dried, the degree of quality expected at the end of the drying process, the drying time and the source of heat, etc. [31]. On the basis of drying methods according to Veerakumar et al. [31], dryers could be classified based on their source of energy as:

I. Mechanical source: Examples are tray dryers, band (Belt) dryers, rotary dryer, roller dryers, fluidized bed dryer, and spray dryers.

II. Electrical source: Examples of such include the dehydrator dryer, oven dryer, and spotlight dryer.

III. Natural convection source: Some examples mentioned include solar tunnel dryer, solar box dryer, cabinet dryer, indirect natural convection and mixed mode type of dryer.

1.6.1 | Types of dryers

There exist a few distinct types of dryers which includes:

I. Tray dryers: These are dryers that are operated mostly in a batch mode which needs continuous loading and unloading of the trays.

II. Band (Belt) dryers: This type of dryer suit materials that are of the range of 5 to 10 mm in size and which cannot be held in a hot airstream. These particles are carried on a belt at a slow speed of about 5 mm/s.

III. Rotary dryers: This mostly has a cylindrical drum that rotates while the materials are fed in through a hopper. The exchange of heat could be achieved by a feeding the heated air into the cylinder or by moving the heated air via a carriage on top of the cylinder or by having a system of tubes in the inside of the cylinder.

IV. Spray dryers: Spray dryers are also called pneumatic or flash dryers. They are mostly needed when the moisture in the material is to be removed rapidly. The principle of operation involves the wet material mixing with the stream of heated air that is conveying it through a drying duct where a rapid transfer of heat and mass occurs thus bringing about the drying.

V. Dehydrator dryer: In a dehydrator dryer, hot air is released and controlled from the top of stacked trays and made to circulate downwards in the sealed compartment.

VI. Solar tunnel dryer: According to Nwankwo et al. [32], solar tunnel dryers consist of long tunnels with a stream hot air. Trucks of wet materials are made to run through these tunnels and the materials get dried as they exit the tunnel. The trucks in the tunnel can be operated through a manual or mechanical means based on the configuration of the trucks and the tunnels.

VII. Solar cabinet dryers: In the solar cabinet dryer, shelves or racks are built inside the drying chamber of the cabinet where hot dry air flows through the on the racks [33]. It operates most suitably under at a temperature value of 70°C, relative humidity of 60%, and air speed of 3.0 m/s.

1.7 | Review of Related Literature

Several scientific and engineering studies have been conducted in order to ascertain the performance and behaviour of several drying systems. Figiel [34] is reported to have observed a drying process for beetroot cubes dehydrated by convective drying in hot air at 60 °C and by the combination of Convective Pre-Drying (CPD) until moisture content 1.6, 0.6 or 0.27 kg/kg db and Vacuum-Microwave Finish Drying (VMFD) at 240, 360 or 480 W. The control samples were obtained by Freeze-Drying (FD).

The drying kinetics of beetroot cubes was described with an exponential function. VMFD significantly reduced the total time of drying and decreased drying shrinkage in comparison with convective method. A critical moisture content divided the temperature profile of samples during VMFD into increasing and falling periods. At the falling temperature period a significant increase in the colour parameters L∗, a∗ and b∗ was found. VM treated samples as well as FD ones exhibited lower compressive strength, better rehydration potential and higher antioxidant activity than those dehydrated in convection. Increasing the microwave wattage and decreasing the time of CPD improved the quality of beetroot cubes dried by the combined method.

Fagunwa et al. [35] developed a device said to be an intermittent solar dryer suitable for the drying of cocoa beans. Drying mechanism was based on a combination of convective heating and direct radiation, with a provision for controlling the rate of airflow through the beans. The experimental model dehydrated cocoa beans from 53.4 to 3.6% moisture content (w.b) in a 72 hours intermittent drying process against ambient temperature and relative humidity in the range 25-30o C and 58-98%, respectively. Quality assessment of the dried beans showed that beans of good quality attributes: Ph of 6.35, acid value of 3.40 mg/g, with mildly bitter taste were obtained under free convective drying; whilst, increase in moisture re-absorption and acidic flavour were indicated with forced convective drying. The work, thus, provided a viable system for producing cocoa beans of good quality attributes, comparable with using the traditional sun-drying, but without the associated drudgery.

An investigation was conducted by Zielinska and Michalska [36] on the drying characteristics of blueberries using Hot Air Convective Drying (HACD), Microwave Vacuum Drying (MWVD) and their combination (HACD + MWVD) on the drying kinetics, colour, total polyphenols, anthocyanins antioxidant capacity and texture of frozen/thawed blueberries. Drying resulted in reduction of total polyphenols content and antioxidant capacity (69 and 77%, respectively). The highest content of total polyphenols was noted after HACD at 90 °C. Drying processes caused a significant decrease (from 70% to 95%) in the content of anthocyanins. The highest content of anthocyanins and the strongest antioxidant capacity was found in blueberries dried using HACD at 90 °C + MWVD. Among drying methods, HACD at 90 °C + MWVD satisfied significant requirements for dried fruits i.e. short drying time and improved product quality.

Jia et al. [37] studied the effect of several parameters on what would become of the drying performance of a pulsed fluidized vibrated bed made of biomass particles. The effects of gas flow rate, bed temperature, pulsation frequency and vibration intensity on drying performance were systematically investigated. While higher temperature and gas flow rate are favoured in drying, there exists an optimal range of pulsation frequency between 0.75 Hz and 1.5 Hz where gas-solid contact is enhanced in both the constant rate drying and falling rate drying periods. The recommendation made at the end of the study suggested that high temperature and high gas flow rate will allow for an effective drying.

Kejing et al. [38] studied some drying characteristics of ginger rhizome using five different drying processes which included hot air drying method, Freeze Drying (FD) method, Infrared Drying (IR) method, microwave drying method, the intermittent microwave, and the convective drying method. Quality attributes of the dried samples were compared in terms of volatile compounds, 6, 8, 10-gingerols, 6-shogaol, antioxidant activities and microstructure. Results showed that Air-Drying (AD) and IR were good drying methods to preserve volatiles. FD, IR and Intermittent Microwave & Convective Drying (IM&CD) led to higher retention of gingerols, TPC, TFC and better antioxidant activities. However, FD and IR had relative high energy consumption and drying time. The outcome also showed that microwave drying and the convective drying method gave positive results when considering the preservation of thermo-sensitive materials, and the advantage of low power consumption.

Then Wang et al. [39] in their work paid attention to the analysis of the mechanism of vibration-energy-transfer using wave propagation in drying. The pressure wave was produced from a vibrating base at the bed bottom and transferred to the particle bed via an air gap formed between the distributor and particle bed. The wave propagation process and its mechanism in a fluidized bed was analyzed. The pressure-wave propagation parameters were numerically calculated from the detected wave signals. The wave propagation velocities were found to be in the range of 9–75 m/s in the experiments. This study had in it the utilization of sensors to better detect the wave signals and to with it estimate the pressure-wave propagation parameters associated with the drying process. In what appeared to be an advancement in the application of technology to drying, Sangster et al. [40] developed a prototype of an automated equipment designed as a cocoa drying house, featuring an automated roof that can be regulated (opened and closed) based on sunshine exposure. It also had an automatic heaters, an automated fermenter and a remote control feature for the automated components heaters which could also be remotely controlled.

2 | Materials and Methods

2.1 | Materials

The following materials was used in the fabrication of the earthen oven with automatic temperature control: mild steel rods, mild steel angle bar, mild steel plate, temperature controller, air blower, thermocouple, insulation fibre and battery. These components were used in the production of the automated clay oven in line with the engineering design developed for the work. However, numerous design considerations were made in consonance with the production needs of the earthen oven.

2.2 | Method

Designing an earthen drying oven using AutoCAD software required a systematic and detailed approach to ensure accuracy and efficiency in the final product. The following design procedure was used as a guide through the process of sketching the oven, taking into consideration the specific requirements and constraints of the project:

I. Defining the design requirements: Before the process was began, it was essential to clearly define the requirements of the earthen drying oven. These include the size, capacity, temperature range and some other specific features that needed to be incorporated into the design.

II. Creating rough sketches: The next step was to create rough sketches of the earthen drying oven using pen and paper. This initial sketch served as starting point for the design process and helped in visualizing the final product. It was important to consider the overall dimensions, shape and layout of the oven in the rough sketch.

III. Initializing AutoCAD software: Once the rough sketch was complete, the AutoCAD software on the computer was opened. AutoCAD is a powerful tool for creating detailed and precise technical drawings, making it ideal for designing complex structures like an earthen drying oven.

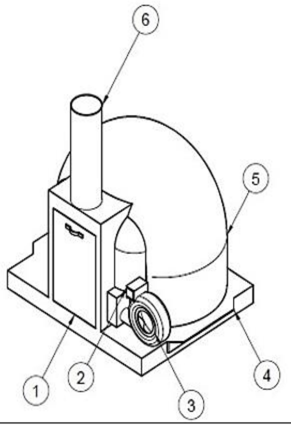
IV. Setting up the drawing environment: Before starting the actual design work, it was important to set up the drawing environment in AutoCAD. This include adjusting the units, grid settings and other parameters to ensure that the drawing is accurate and to scale. Layers were created for different elements of the design to keep the drawing organized.

V. Drawing the basic structure: Using the rough sketch as a reference, the basic structure of the earthen drying oven was sketched in AutoCAD. This include creating the walls, roof, door and other essential components of the oven. The dimensions and proportions were given close attention to ensure that the design is accurate.

VI. Details and features: Once the basic structure was in place, details and features to the design was added to enhance functionality and aesthetics. This included ventilation openings, insulation layers, drying chambers, shelves and other elements that were necessary for the proper operation of the oven. AutoCAD's tools and commands were used to create these details with precision.

VII. Review and revise: After completing the design, a review of the drawing was carried out carefully to identify any errors or areas that need improvement. Necessary revisions to ensure that the design meets the requirements and specifications set at the beginning of the project. It was important to pay attention to details and adjustments made as needed to achieve a high-quality final product.

Designing an earthen drying oven using AutoCAD software required a systematic and detailed approach to ensure accuracy and efficiency. By following the aforementioned design procedure, the earthen oven with labels, dimensions and layouts (*Figs. 7-9*) were created with precise and functional design that met the specific requirements of the project.



S/N	ITEM	DESCRIPTION
6	CHIMNEY	MS
5	OVEN BODY	CLAY
4	HANDLE	MILD STEEL
3	BLOWER	BOUGHT OUT
2	TEMPERATURE CONTROL	BOUGHT OUT
1	INSULATED OVEN DOOR	MS

PARTS LIST

Fig. 7. Clay oven with parts.

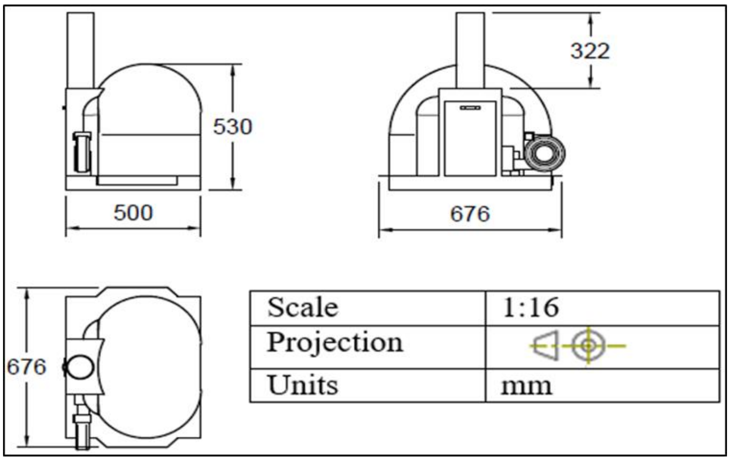


Fig. 8. Clay oven with dimensions.

Fig. 9. Clay oven drying chamber.

Fig. 10 shows the skeletal framework of the Oven. After applying all the methods outlined, the earthen oven was produced as shown in *Fig. 11*.

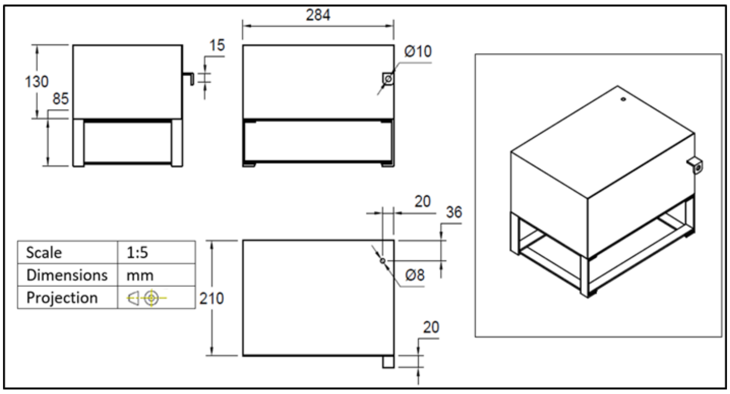


Fig. 10. Skeletal framework of the oven.

Fig. 11. Produced earthen oven.

2.3 | Procedure for Fabrication of Earthen Drying Oven

Detailed procedure for fabrication of the earthen drying oven are as follows:

I. Site selection: The first step in the construction of the earthen drying oven was to select a suitable site. The site was flat, well-drained, and away from any flammable materials. It was also located close to a source of fuel, such as wood and charcoal.

II. Gathering materials: The materials needed for the construction of the earthen drying oven include clay soil, sand, straw, water, and bricks or stones for the base. These materials were easily sourced from the local environment.

III. Mixing the clay: The next step was to mix the clay soil with sand and water to create a workable clay mixture. The clay was mixed thoroughly to ensure a uniform consistency. The laboratory analyses were performed according to British standard methods of test for clay soil (BS 1377: Part 1-9, 1990).

IV. Building the base: Using bricks and stones, the base for the oven was built. The base was sturdy and level to support the weight of the oven.

V. Constructing the walls: Using the clay mixture, the oven wall was built. The walls was thick enough to retain heat but not too thick to inhibit airflow. Straw was incorporated into the clay mixture to add strength to the walls.

VI. Creating the drying chamber: Once the walls was complete, a drying chamber was created inside the oven. This chamber was large enough to accommodate the materials to be dried but not too large to lose heat.

VII. Installing the roof: Finally, a roof for the oven was constructed using the clay mixture. The roof was sloped to allow for rainwater runoff and was sealed to prevent heat loss.

Constructing an earthen drying oven is a simple and cost-effective way to dry various materials. By following the step-by-step detailed practical procedure outlined above, individuals can easily fabricate their own earthen drying oven using locally available materials. This environmentally friendly alternative to modern drying methods is not only sustainable but also promotes self-sufficiency and resourcefulness.

3 | Results and Discussion

Table 1. Table of values for the test conducted for 10, 15, 20, 25 and 30 minutes at 2m/s airflow rate.

Mass of Charcoal (Kg)	Initial Temperature(˚C)	Final Temperature (˚C)	Heating Time (Min)
10 minutes at 2m/s airflow rate			
5	200	280	10

Table 1. Continued.

Mass of Charcoal (Kg)	Initial Temperature(˚C)	Final Temperature (˚C)	Heating Time (Min)
10 minutes at 2m/s airflow rate			
10	210	288	10
15	220	295	10
20	230	295	10
25	240	300	10
15 minutes at 2m/s airflow rate			
5	205	288	15
10	215	289	15
15	225	292	15
20	235	298	15
25	245	300	15
20 minutes at 2m/s airflow rate			
5	210	291	20
10	220	298	20
15	230	299	20
20	240	300	20
25	250	300	20
25 minutes at 2 m/s airflow rate:			
5	215	293	25
10	225	298	25
15	235	300	25
20	245	300	25
25	255	300	25
30 minutes at 2 m/s airflow rate:			
5	220	295	30
10	230	300	30
15	240	300	30
20	250	300	30
25	260	300	30

Table 2. Table of values for the test conducted for 10, 15, 20, 25 and 30 minutes at 3m/s airflow rate.

Mass of Charcoal (Kg)	Initial Temperature(˚C)	Final Temperature (˚C)	Heating Time (Min)
10 minutes at 3m/s airflow rate			
5	201	291	10
10	211	293	10
15	217	294	10
20	226	298	10
25	230	300	10
15 minutes at 3m/s airflow rate			
5	208	295	15
10	212	298	15
15	216	299	15
20	220	299.6	15
25	224	300	15
20 minutes at 3m/s airflow rate			
5	203	298	20
10	207	299	20
15	211	300	20
20	215	300	20
25	219	300	20
25 minutes at 3m/s airflow rate			
5	204	297	25
10	208	299	25
15	212	300	25
20	216	300	25
25	220	300	25

Table 2. Continued.

Mass of Charcoal (Kg)	Initial Temperature(˚C)	Final Temperature (˚C)	Heating Time (Min)
30 minutes at 3m/s airflow rate			
5	205	298	30
10	209	300	30
15	213	300	30
20	217	300	30
25	221	300	30

Table 3. Table of values for the test conducted for 10, 15, 20, 25 and 30 minutes at 4m/s airflow rate.

Mass of Charcoal (Kg)	Initial Temperature(˚C)	Final Temperature (˚C)	Heating Time (Min)
10 minutes at 4m/s airflow rate			
5	200	295	10
10	209	298	10
15	211	299	10
20	219	300	10
25	221	300	10
15 minutes at 4m/s airflow rate			
5	202	296	15
10	210	299	15
15	216	299.6	15
20	218	300	15
25	224	300	15
20 minutes at 4m/s airflow rate			
5	201	299	20
10	213	300	20
15	218	300	20
20	221	300	20
25	223	300	20
25 minutes at 4m/s airflow rate			
5	203	297	25
10	214	300	25
15	219	300	25
20	222	300	25
25	225	300	25
30 minutes at 4m/s airflow rate			
5	204	298	30
10	216	300	30
15	220	300	30
20	223	300	30
25	226	300	30

3.1|Effects of Charcoal Mass on Earthen Oven Heating Time

The heating time of an earthen oven is a critical factor in determining the efficiency and effectiveness of the cooking process. Charcoal is a commonly used fuel for heating earthen ovens due to its high heat output and long burning time. The mass of charcoal used in an earthen oven has a significant impact on the heating time. In this study, the charcoal masses ranging from 5 to 30 kg was tested to determine the optimal mass for efficient heating of an earthen oven. The charcoal was weighed and placed in the oven, and the time taken for the oven to reach a specific temperature was recorded. This process was repeated for each mass of charcoal, ranging from 5 to 30 kg. The data collected (*Tables 1-3*) was analyzed to determine the relationship between charcoal mass and heating time. The results showed a clear correlation between charcoal mass and heating time. As the mass of charcoal increased, the heating time of the oven decreased. This is because a larger mass of charcoal generates more heat, resulting in faster heating of the oven. Specifically, using 30 kg of charcoal resulted in the shortest heating time, while using 5 kg of charcoal resulted in the longest heating time. This demonstrates that a larger mass of charcoal is more efficient in heating an earthen oven quickly and effectively.

3.2 | Effects of Air Flow Rate on Charcoal Burning Rate in Earthen Oven

In this study, the burning rate of charcoal in an earthen oven at different air flow rates of 2, 3, and 4 m/s was measured. An experimental setup consisting of an earthen oven with a charcoal burner was designed. The burning rate of the charcoal at air flow rates of 2, 3, and 4 m/s was measured using a digital thermometer. The burning rate was determined by measuring the weight of the charcoal before and after the experiment. The results showed that the burning rate of charcoal in the earthen oven increased with an increase in air flow rate. At an air flow rate of 4 m/s, the burning rate was significantly higher compared to the rates at 2 and 3 m/s. This implies that a higher air flow rate promotes more efficient combustion and leads to a higher burning rate of charcoal. Hence, a higher burning rate means that the charcoal will be consumed more quickly, leading to the need for more frequent refuelling. On the other hand, a lower burning rate may result in incomplete combustion, leading to the production of harmful pollutants such as carbon monoxide. One of the key factors that influence the burning rate of charcoal is the air flow rate within the oven. When air is supplied to the charcoal at a higher rate, it promotes more efficient combustion, leading to a higher burning rate.

3.3 | Effects of Oven Temperature on the Properties of Earthen Oven Clay Walls

In this study, a physical observation was carried out on the earthen oven. As observed, the temperature at which the earthen oven is heated can have a direct impact on the structural integrity and thermal properties of the clay walls. When the oven is heated to a high temperature, the clay walls became more porous and brittle, leading to a higher risk of cracking or collapsing. Higher temperatures may result in increased thermal conductivity, allowing for more efficient heat transfer and drying. However, if the temperature is too high, it may lead to uneven heating and hot spots within the oven. On the other hand, heating the oven to a lower temperature resulted in a denser, more stable clay wall. It was important to carefully consider the temperature at which the oven is heated in order to ensure the structural integrity, thermal properties, and overall efficiency of the oven.

4 | Conclusion

The findings from this study on a fit for purpose earthen oven for drying basic household consumables in rural areas have provided valuable insights into the potential benefits and challenges of this technology. The study has shown that earthen ovens can be an effective and sustainable solution for drying a variety of household consumables, including fruits, vegetables, grains, and herbs. One of the key advantages of using an earthen oven for drying is its low cost and accessibility, making it a viable option for rural communities with limited resources. Additionally, the use of earthen ovens can help reduce the reliance on fossil fuels and electricity, contributing to environmental sustainability. However, it is important to note that there are also challenges associated with the use of earthen ovens for drying. These include the need for proper maintenance and upkeep of the oven, as well as the potential for contamination of the dried consumables if proper hygiene practices are not followed. With proper planning and implementation, earthen ovens can be a sustainable and cost-effective solution for addressing food security and waste management challenges in rural areas. Further research is required to explore ways to optimize the design and functionality of earthen ovens for drying purposes, as well as to address any potential health and safety concerns.

Author Contribution

Otobong Okon Ite contributed to the conceptualization, methodology design, and overall direction of the study. He also took the lead in writing the manuscript.

Ubong Kingsley Emmanuel was responsible for data analysis, interpretation of results, and assisted with manuscript revisions.

Bernard Felix contributed to the literature review, prepared the figures and tables, and supported the editing and proofreading of the manuscript. All authors discussed the results and contributed to the final manuscript.

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Data Availability

We encourage all authors to make their research data available. Please indicate where the data supporting the reported findings can be found, including links to publicly archived datasets that were analyzed or generated during the study. If no new data were generated or if data are not available due to privacy or ethical restrictions, an explanation is still required. The suggested data availability statements were collected in DAS file.

Conflicts of Interest

There are no Conflict of Interest to declare concerning the content of this manuscript

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