Re-imagining Professionalism: Applying Thermos Flask Designs to Waste Heat Recovery Chambers (WHRC) in Kilns

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Abstract

Efficiency and effectiveness are taken into consideration on the basis of the type of kiln that the ceramists want to build. Efficiency (energy savings of kiln structure) and Effectiveness (quality of firing and fired products). Kilns are insulated machines that turn clay products into complex, lasting objects. For emerging ceramics/pottery studios, centers, and industries, problems associated with the poor insulation of a kiln can lead to heat loss and waste, which can be problematic. Kiln structures can also be modified through incorporating waste heat recovery chambers (WHRC) to reduce heat losses in kilns. The modification is based on principles of a thermos flask and this allows the WHRC to recycle waste heat from primary firings to further increase efficiency of the overall firing process. The study adopted an experimental and descriptive research approach, and the findings revealed that the modified kilns could attain sufficiently high temperatures for ceramics/pottery production. This method of kiln construction conserved energy and reduced possible greenhouse emissions. The study used effective bricks that remedied waste heat issues in kilns. This invention acmes the prerequisite for innovative concepts aimed at improving professionalism in the visual arts and material sciences.

Keywords: Energy Conservation, Recovery Chambers, Secondary Energy, Thermos Flask, Waste Heat, Kiln Construction.

Introduction

The COVID-19 pandemic and its aftermath had a significant effect on Nigeria's socio-economic growth (Seo et al., 2023), impacting many aspects of the country's economy and society. One of the major problems has been the disruption of the economy, leading to job losses and significant decreases in incomes. Lockdowns forced many SMEs to close down their businesses or reduce their working hours, leading to increasing poverty among people and reducing their income opportunities (Usman et al., 2024; Ojie-Ogwu, 2021; Nweze and Nnadi, 2021). In recent years the Nigerian economy has faced a crisis from a sharp fall in oil prices, security challenges from insurgent violence and competition for resources. The pandemic has worsened the situation, pushing the Nigerian economy into a recession. As a result, Nigeria is among the countries with the highest rates of multidimensionality poor individuals in the world (United Nations Development Program (UNDP) & the National Bureau of Statistics (NBS), 2021). As Nigeria works to recover from the devastating influence of the COVID-19 plague on its economy, the government has also begun focusing on several sectors that were previously neglected in its efforts to revitalize the national economy through ceramic production. According to Isaac (2021), the ceramic sub-sector seems most promising, because it offers a range of industrial products that can boost the economy of any nation to another level of growth. Nigeria is blessed with the needed raw materials, and it is in abundance around the country. These materials includes kaolin, which is among other important raw material that is used in the production ceramic/pottery wares (Issac, 2021).

Kaolin, along with other materials used in pottery production, is abundant on Earth and is available in almost all parts of the world (Adindu et al., 2014). One important characteristic of kaolin lies in its purity, it is mostly free of inorganic material which acts as impurities, altering its original colour. Due to its unique properties, making the earthly mineral, a sought-after material for the production of ceramic wares in a mixture with other earthly minerals such as feldspar, talc, Bentonite, calcium carbonate, and flint/quartz/silica, for the production of stoneware, Porcelain, etcetera. The recipe from the mixture allows for the creation of high-quality ceramic wares, which can be used for both home use and varied industrial applications. Between 1960 and 1986, the accessibility of clay/ceramic materials led to the creation of numerous ceramic manufacturing outfits, ranging from small-scale to medium and large enterprises by governments, private investors, and foreign partners in a proposition to boost the nation's economy. These industries produced earthenware and stoneware products for household use and building construction. This led to significant local and international demand (Isaac, 2021). However, the plodding closure of many of these ceramic sectors due to the Structural Adjustment Program (SAP) of 1986 led to a decline in artistic development, and in the ceramic/pottery market.

Due to this adjustment, the once-thriving industrial economy experienced deficient government policies, leading to an increased reliance on importation and smuggling across borders. Potters and ceramic centers were left to fend for themselves, resulting in the cessation of many industrial and pottery studio activities. This situation likely triggered a shortage of skilled professionals in the ceramic manufacturing subsector, as these experts may have sought other sources of livelihood for themselves and their families. Additionally, the lack of electricity supply to power equipment and machinery, along with a heavy dependence on imported machinery and replacement parts, brought a halt to the ceramic subsector (Isaac, 2021). The remaining outfits that were still able to produce under harsh conditions had to increase the price of their products to remain in the market, which was not a feasible decision for a country in need of an economic boost. The high demand for ceramic products in Nigeria, was influenced by the accessibility of ceramic raw materials in the country. The availability of these materials led to the emergence of indigenous potters and pottery centers, improved curricula for institutions offering ceramics, and a robust industrial bustle. However, the lack of proper heat retention systems in their kilns, high energy consumption, and outdated technology caused problems for these studios, ceramic/pottery centers, and industries. These setbacks may have also funded the decline of ceramic practices and production in Nigeria alongside the energy-generating factors.

The lack of reliable electricity in Nigeria caused many ceramic production businesses to seek alternative energy sources for their kilns, furnaces, dryers, and ovens. This steered the use of indigenous technology, which is still developing. Other alternative energy sources include solid and liquid fuels such as firewood, coal, LPG, waste engine oil, kerosene, diesel, peat, bitumen, and propane. However, some of these energy sources can be expensive and may not provide enough energy for proper combustion for firing, leading to unanticipated problems. Odewale et al. (2013) identified that Nigeria's ceramic production, design, and technology research are hindered by poor and inadequate power supply. These researchers explained that Nigeria's power supply system is similar to its counterparts in other developing countries, and it is characterized by deficient available capacity, (Frank, 2003). This mainly could be as a consequence of inadequate electrical power supply, the state of deteriorating machinery and equipment, and deficient national infrastructural facilities (Okoye, 2003).

In order to determine the economic feasibility of using secondary energy for combustion and how to recover the waste heat generated, several factors, questions, and decisions regarding waste heat chambers in kilns were observed. Some of the questions that need to be addressed include:

i. What are the best ways to recover and utilize waste heat?
ii. Identify the source of the waste heat and determine how it is generated (from liquid, solid, gas burners, or electricity).
iii. Assess the availability of the waste heat (continuous or periodic generation).
iv. Evaluate the temperature of the waste heat over time, considering changes in material composition and chamber construction; (Potency of the heat, low, medium or high).
v. Select appropriate design principles for building a waste heat recovery chamber in kilns.

vi. Determine the essential location for the kiln building (industrial or residential areas).

The economic feasibility of waste heat recovery chamber design in a periodic kiln is determined by the answers to certain questions. No formal research has been conducted on incorporating waste heat recovery chambers in downdraft periodic kilns. However, some researchers and organizations believe that many high-temperature waste heat sources can be easily captured and utilized with existing technologies. In contrast, other sources of heat need to be cleaned before use. Depending on the functions of the recovered heat, removing contamination may also result in the loss of heat. The goal of this study is to address the issue of heat loss in kilns. To accomplish the aim of the research, the structure of the kiln will be modified using principles of thermos flask design as concepts for creating waste heat recovery chambers. The waste heat produced by the primary energy source is expected to aid in the overall firing process of the kiln. The study has specific objectives, including identifying the categories of kilns which can adapt waste heat recovery chambers design, developing an economical design, sourcing materials that can produce heat retention properties similar to thermos flasks, and determining the category of recoverable temperature.

Review of Related Literature

Energy plays a crucial role in boosting the Human Development Index (HDI) of a country. As such, the progress and development of mankind have always perceived energy as a key, as it has enabled the progression of technology to meet human requirements. Energy is the engine of technological, economic, and educational development in any country, to which global competitiveness leads (Manrique et al., 2018). For a lot of reasons, energy is critical in industrial applications. To begin with, energy is the driving force behind every single manufacturing or production process. It powers machinery, production lines, and it is essential for the creation and processing of materials. Energy keeps the world running because it’s used in everything from heating to cooling, to powering complex machinery used to convert raw materials into finished products. Moreover, on a larger scale, energy efficiency can play a big role in drastically cutting down the operating expenses. As energy consumption can be a major source of overheads in manufacturing process, efficient use of power can translate to a huge financial gains. Consequently, it can lead to greater competitiveness of an industry in the global market eco-sphere. Additionally, the rate and type of energy consumed in industrial processes, will have a significant impact. For example, Sosialova et al., (2020), Ritchie & Roser (2018) noted that heavy use of fossil fuels can result in high greenhouse gas emissions, which contribute to climate change. As a result, industries are shifting more towards green energy and solutions to decrease their carbon footprint and comply with environmental regulations that will preserve human life and the environment in which they exist. Sustainable energy practices can ensure that a company is not only compliant with the environmental and safety standards that governments lay down, but more cost-effective too, with responsible alternatives becoming better and cheaper as technology improves. Innovation forges the way toward green energy and energy efficient technologies, resulting in the creation of new products and processes which bring energy resources to bear more effectively.

Ceramic kiln is a high-temperature, specially designed oven for firing clay pieces or ceramic objects that is capable of reaching as high as 1400 degrees and even more temperatures; to bake clay object to become permanent, hard and rocklike. The closure acts on the heated clay, exposed to different heat cycles that varies depending on the type of materials (clay and glaze specimen) which is being fired. Previously, in the absence of kilns, prehistoric potters depended on the hardening of clay containers, vessels and objects in open bonfires or fires in pit (Agumba & Abbott, 1996) as a prelude to more advanced technologies. With time, kiln became enclosed structures that could attain higher and consistent temperatures, which allowed the production of more sophisticated ceramics (Ozidede et al., 2025). Kilns are traditionally constructed with materials of terrestrial origin, but only those that char under heat serve as insulators that prevents heat transfer to the kiln walls through conduction (Ojie-Ogwu & Ozidede, 2021; Oteng, 2011). For energy to be properly harnessed, kilns need to be properly constructed and operated for improved efficiency, and this can be ascribed to any level of the ceramic sector. Kilns have proven themselves to be economical in capital cost, reasonable labor requirements, and capable of producing high-quality ceramic and pottery suitable for industrial applications and domestic use over decades of innovation. Kilns are structures capable of containing heat generated by burning fuel or electric resistance through elements.

To further understand the ideas of kiln construction and insulation, the researcher based his ideas on Rhodes's (1968) assertion that kiln building has become a well-established field, calling for innovations to enhance reliability and energy efficiency. Rhode's emphasis is on the requirement for a sustainable and efficient structure that can withstand the test for a successful firing. According to Ojie-Ogwu & Ozidede, (2021), the kiln should be a simple and understandable plan that even layperson can comprehend without stress or proper supervision, and should also include thermal resistance shock, mechanical stresses, weathering concerns and considerations. Han (2010) and Eke (2007) have confirmed that these qualities are essential for achieving energy efficiency and cost-effective kiln building and operations, as stated by Rhodes (1968). Energy usage in industrial applications has emerged as one of the critical elements in all phases of the industry, and the ceramic subsector is one of them in this aspect. Ceramic production in industry is known for its high energy consumption during the production processes, which makes it the industry that is always seeking energy-saving and environmentally friendly approaches to the processes (Almeida, 2022). Several initial stages require considerable energy for handling raw materials involved in the process of manufacturing. Such processes include drying the quarried materials, grinding and mixing, kneading, molding, and firing or sintering. Furthermore, a significant amount of thermal energy is required to facilitate endothermic reactions for the chemical transformation of materials, which occurs while firing (bisque and glaze) (Jouhara et al., 2018). These two thermal phases of firing ceramic products consume the significant majority of the energy expenditure in industrial applications.

In ceramic industry, the routine of using waste heat recovery units has been famous as an effective way of combating wasted energy in response to achieving energy efficiency goals (The Engineer, 2016). To discover the waste heat potential, it is essential to identify ways in which the recovered waste heat can be explored and utilized. It is imperative to pinpoint and investigate the effectiveness of waste heat recovery technologies and their sources (Oskouian, 2015). UNIDO & ECC (1994) reports on the use of electrical and chemical energy in the form of fuel are some of the types of energy mostly used in the ceramic sector. Electrical energy is used to power the motors of the production equipment and machines. In contrast, chemical energy in the form of fuel is employed to provide thermal energy to heat kilns, furnaces, and other related equipment (Jouhara, 2018).

Typically, ceramic manufacturing consists of several stages. The first stage is characterized by the mixture of raw materials and the inclusion of other additives which produces a slurry pasty material after being grounded and mixed using heavy duty ceramic machinery. The material slurry is then fed into a drying tower where it is dried and converted to powder, which can be pressed into a form or shape, forming an unfired ceramic ware. This then passes to another drying operation through a hot chamber where controlled heat allows the product to lose the water content inhibited in it before these formed materials can be fired in a kiln. The kiln is an equipment that is used to create a blank ceramic surface which will be embellished or decorated to taste by the ceramic artists, to meet traditional or for contemporary use. After this stage, the product is then sent to a polisher to achieve a smooth surface. The two energy-consuming operations in ceramics that produce the most emissions are the drying and firing processes (Peng et al., 2012).

There are two types of water present in the clay, they are known as bound water and free water (Zhang et al., 2022). The physical water also known as the free water, is added to clay to form a plastic homogeneous mixture. This water, which is usually table or drinking water, is essential for making the clay malleable for potters and ceramic artists. Without this malleable phase, ceramic work cannot be produced. The importance of water in forming ceramic products cannot be overstated, as it is the second most crucial phase in creating a workable clay body for pottery production. The clay is identified, excavated from its location, and then brought to the studio. The purpose of mixing the clay with water, aside from making it malleable, is to create a consistent mixture. The chemical water also known as the bound water in clay refers to the water bound within the clay's chemical structure. During the formation or sedimentation process, organic and non-metallic minerals or oxides make up this compound. When the chemical water is removed from the clay body, it goes through a stage called quartz inversion. This process, as explained, transforms the clay from a pliable state to a stiff, rocklike state that becomes impervious to acid and water after firing. The firing stage is the largest consumer of energy in the ceramic production process and contributes to almost 50% of energy loss through flue and chimney (Delpech et al., 2017; Jouhara et al., 2018; Zdeb et al., 2019). During this stage, the structural integrity of ceramics, encompassing mechanical strength, abrasion resistance, dimensional stability, resistance to water, chemicals dispersion, and heat resulting from elevated temperatures, typically between 750°C and 1800°C begins to change (Mezquita et al., 2014). Firing ceramic bodies is complex due to the mixtures of various materials. The optimal firing schedule for a body is influenced by factors related to its composition, preparation, firing methods, and glaze (Singer and Singer, 1963). The physical and chemical transformations caused by heat on the different raw materials and their mixtures in the kiln will either burn out or change phase as the temperature increases (Singer & Singer, 1963).

Principles of Vacuum Flasks

Vacuum flasks are insulating storage vessels that significantly prolong the duration over which their contents remain hotter or colder than the flask's surroundings (Soulen, 1996). A vacuum is a space from which air and gasses have been removed from a gas-containing volume (Niels, 2017). Ulrich et al., (2011) suggest that the principles behind thermos flasks can also be adapted and utilized for thermally insulating buildings. The insulation can be achieved by employing a vacuum, with materials like panels made of compressed silica powder enclosed in a gas and water vapor-tight envelope made of special barriers, films, or stainless steel. These thermal insulation materials aim to reduce heat transfer caused by temperature differences.

Modes of Heat Transfer

When matter absorbs radiant energy, it heats up and develops a temperature gradient. This leads to either molecular motion (conduction in solids) or mass motion (convection in gases and liquids) (Kelly, 1931). All substances, including air spaces and building materials such as wood, glass, plaster, insulation, and so on, must adhere to the laws of nature when it comes to heat transfer. Solid materials differ only in the rate of heat transfer, which is mainly affected by differences in density, weight, shape, permeability, and molecular structure.

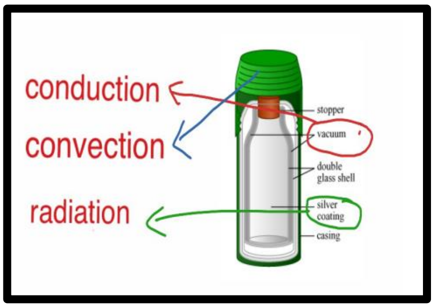

Figure 1. Configuration of a Thermos Flask,
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There are three modes of heat transfer: conduction, convection, and radiation. The primary mode of heat transfer using electricity is radiation. At the same time, conduction and convection are secondary and come into play only when matter interrupts or interferes with radiant heat transfer using liquid fuels and gas (Johnson et al., 1931). Heat transfer inside kilns happens through conduction, convection, and radiation and can occur outside, inside, and across the kiln walls. The significance of each mode of heat transfer depends on factors like the properties of the solid, gas, and kiln walls, kiln design, and operating conditions (Hwan, 2009).

Waste Heat Recovery Systems: An Overview

While Waste Heat Recovery (WHR) systems have been in use since the 1920s, the technology has been rapidly progressing in recent years, making it a credible sustainable power generation option (Exergy, 2022). Waste heat is produced by processes via the burning of fuels or chemical reactions and is often wasted into the environment, although it can be used for other processes. The amount of waste heat is less important than the value of it. Heat recovery from waste heat gases varies depending on the temperature and economics of the heat recapturing process (Reay and Span, 1979).

WHR methods involve capturing waste heat from a process to be used as an additional source of energy, which can be used to create extra heat for equipment or to generate electrical and mechanical power (Naikk-Dhungel, 2012). According to McKinsey (2010), increasing energy efficiency is cost-effective and easily implemented, and reducing energy costs begins with using less energy. Heat chambers in kilns play a crucial role in WHR, and factors like life cycle, building costs, and maintenance significantly impact the profitability, efficiency, and effectiveness of recyclable waste heat. While compact heat chambers are not common in ceramic industries, there are alternative ways to recover heat in kilns without altering the original design. Industries are faced with the challenge of reducing greenhouse emissions and improving machinery efficiency due to rising fuel prices and environmental concerns. Waste heat recovery systems are being researched as a key area to lower fuel consumption, decrease harmful emissions, and improve efficiency (Jouhara et al., 2018). Waste heat can be classified into high, medium, and low-temperature grades, and WHR systems are tailored for each range of waste heat to achieve optimum efficiency (Burckner et al., 2008). Rejected waste heat can be at any temperature, but higher temperature waste heat is of better quality and easier to optimize (The-Crankshaft Publishing, 2017).

A large amount of hot flue gases is generated from boilers, kilns, ovens, dryers, and furnaces; if some of this waste heat could be recovered, a considerable amount of primary fuel could be saved. Although the energy lost in waste gasses cannot be fully recovered, however much of the heat could be reclaimed and loss minimized by adopting waste recovery mechanisms that pertain to the use of ceramic kilns and the environment in which the equipment is built. According to Reay and Span (1979), in any heat recovery situation, it is essential to know the amount of heat recoverable and also how it can be used. Usually, the higher the temperature, the higher the quality and the more cost-effective the heat recovery process will become (Teng et al., 2007).

Challenges and Opportunities for Low-temperature WHR Systems

Recovering waste heat is more feasible and easier when temperatures are in the medium to high-temperature range (Naik-Dhungel, 2012). There are vast opportunities for recovering waste heat in the low-temperature range, as most industrial WH is in this category (Haddad et al., 2014). Nevertheless, recovering low-temperature WH is found to be more challenging than the medium to high temperatures. The reason allocated for this is mainly associated with the method of collecting the WH (Wang, 2013). For instance, water vapor exists in low-temperature exhaust gases, and it tends to cool down, mix with other particles, and then deposit corrosive solids onto the heat exchanger surface (Ganapatha, 2015).

The heat exchanger's surface has to be cleaned or replaced regularly to maintain the functionality of the heat exchanger, this process can be uneconomical. Salazar-Villalppando et al., (2012) suggest that the use of advanced materials and methods that can minimize corrosion and reduce the need for regular maintenance be considered first before embarking on construction and utilization of the WHR process in any kiln. Fraga (2009) states that as the heat transfer rate is low when recovering low-temperature WH, large heat exchangers may be required to achieve optimal heat transfer. This is mainly because convective heat transfer rates are functions of temperature differences between two locations and the area through which heat is transferred. Burn, Friedman, and Dennis (2017) gave insight into the cost of equipment used to recover heat from low-temperature applications may be less, as lower WH temperatures allow the use of less expensive materials. Nonetheless, the main challenge with low-temperature WHR can be finding use for the recovered heat. Potential uses for low-temperature WH can include a heat pump to improve and increase the efficiency of heat to a higher temperature, thereby using the waste heat to produce domestic hot water, space heating, and process heating (Salazar-Villalppando et al., 2012; Dunning and Katz, 2017).

Benefits of WHR Systems

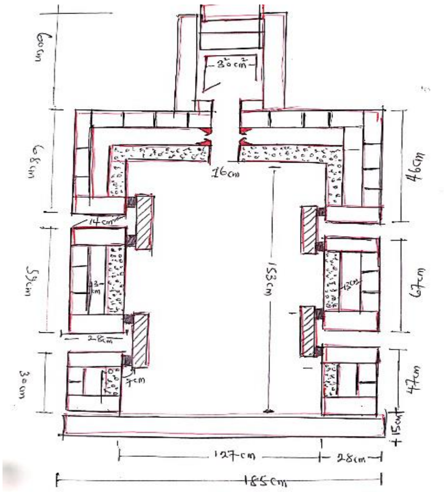
The benefits of WHR can be broadly classified into direct and indirect benefits. The direct benefits of WHR have a direct impact on the efficiency of the process. This is reflected by the reduction in utility consumption charges and process costs. The indirect benefit includes the reduction of pollution, as many combustible wastes and other chemicals released into the atmosphere when burnt serve to recover heat and reduce environmental pollution to some level. Another indirect benefit is a reduction in equipment sizes, as WHR reduces fuel consumption, which leads to a reduction in the flue gas produced. This result leads to a decrease in equipment sizes of all flue gas handling sections.

Materials and Method

The research is studio-based and uses the experimental and descriptive methods. It involves acquiring raw materials such as dense and perforated bricks, ceramic wool, aluminum foil paper, ceramic blankets, silica, and pottery shreds for the production of waste heat recovery chambers in kilns. Bricks were formulated according to specific recipes and a suitable sample was selected for constructing the kiln. Bricks were prepared based on a series of appropriate recipes, and a particular sample was chosen to build the kiln. 3D technical drawings and preliminary designs were developed to find the best model for the chambers to reuse waste heat from a periodic kiln Combinations of different fuel sources, such as gas (kerosene), wood, waste oil, were burned with compressed air. The kiln test runs were run under a range of atmospheric conditions that were then observed and documented.

Developing the WHR Chamber in Kilns

Construction of a waste heat recovery chamber in the kiln is a major consideration for WHR system development. This process involves analyzing the layout diagram and creating the recovery chamber, which facilitates the identification of the source of and the sink for the waste heat, the possibility of upset conditions due to the introduction of WHR chamber to the setup, availability of space for kiln construction and any other limitations that may arise post construction and installation.



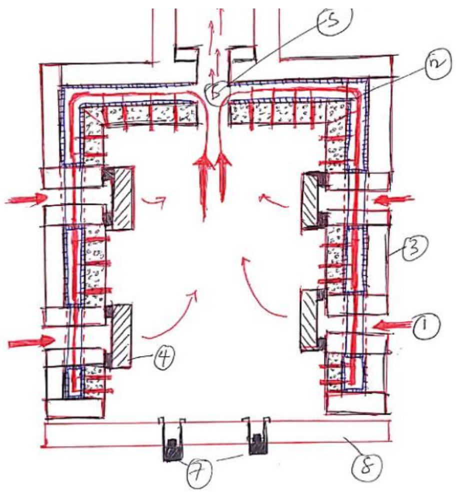


Figure 2. Kiln plan and Dimensions

Figure 3. Anatomy of a WHR Chamber: 1). Primary energy (fuel for combustion), 2). Secondary fuel in the combustion chamber, 3). Insulating wall (dense brick), 4). Bagwell, 5). Flue, 6). Chimney, 7). Spy-hole, 8). Kiln door.

And heat recovery can only be beneficial if the heat can be reused. For design to be justified and innovative, the recovered heat should contribute to overall energy efficiency and effectiveness. It goes without saying that before investing and constructing a kiln using the WHR chamber, one should analyze all benefits as well as profitability of the project. Fuel savings and kiln design efficiency are two important aspects of almost every production ceramist's investment decisions. While most kiln designs enable different ways to use recovered energy, the best alternative depends on the kiln specifics, the site characteristics and the energy prices at which the kiln is running. When plan passes the criteria and is approved by related organization, kiln firing fuel consumption will be decreased.

Figure 4. Alternate Laying of Bricks

Figure 5. Starting the Kiln Walls

Calculating Downdraft Kiln Size Volume and Stack Area Kiln volume from this research is L-127 cm x B-153 cm, while overall kiln size is L-246 x B-186 cm x H-153 cm. Perforated refractory brick at different dimensions makes up the interior walls, while dense insulating bricks form the outer shells. The construction of the kiln requires some knowledge of specialized masonry skills and a certain number of rules to respect, in order to obtain a robust and thermal and resilient structure in the face of high temperatures. Like in a house, the bricks should be laid in a stretcher course with no bricks directly over each other. Stretcher course: (as their name suggests), lay longways (run with the walls) of the structure and are not to exceed 60.3 cm high without being supported. Alternate joints on a row are also recommended to serve as expansion joints during the fuming process.

Figure 6. Designing the firebox **Figure 7.** Completed recovery Chamber

Mortar mixed to the consistency of pancake batter should be applied using a trowel to lay the bricks. A thin coat of mortar (0.32 – 0.5cm) between bricks is sufficient to hold them together for the next course. Additionally, bricks can be dipped in mortar prepared to a syrup-like consistency to lay them effectively.

Figure8. Re-enforcing kiln walls with Pillars **Figure 9.** Insulating Chamber with Spacers and Aluminum foil

The mortar in this research was made locally from materials that could be found around the researcher's studio. The mortar used contained 200 kg of workable plastic clay, 20 kg of sieved sharp sand, 323 kg of grog (from ceramic fragments), 255 kg of kaolin, 7 liters of sodium silicate, and 55 liters of water. The mortar was then allowed to stand for two weeks so it had properly mixed before use. The kiln consisted of two brick layers for both its walls and floor.

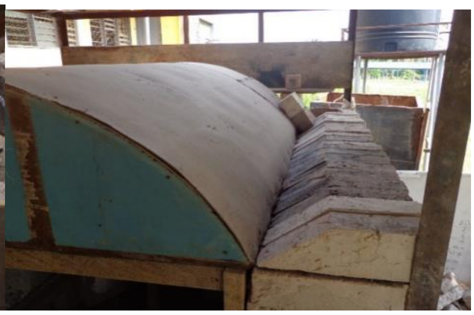


Figure 10. Top View of the WHR Chamber **Figure 11**. Arranged Skewback on Mould

To cover the WHR chamber, an arch form was built. The kiln arch serves multiple purposes – it forms a roof for the kiln, acts as a door, and provides a cover for the recovery chamber. A sprung arch design was chosen for this research. The design appears as a cylinder, and it is a frequent arch for kiln building. The arch is supported by a skewback on each side of the kiln. This arch rise is defined by the skewback, which attaches to the kiln (see Figure 11).

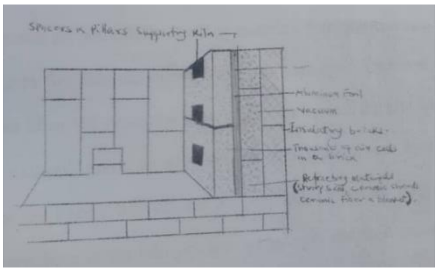


Figure 12. Completed Arch Form **Figure 13.** Schematics and Illustration of the WHR chambered kiln.

The pressure of the arch pushes downward and outward against the wall. If the arch is not supported by the skewback against the kiln, the arch can shift and maybe collapse. Both the walls and arch, therefore, must be built stiff enough to satisfy the thermal requirements of the chambered kiln.

Table 1: *Similarities between the Thermos Flask and the WHR Chambered Kiln*

Thermos Flask		WHRC Kiln
1.	The outer shell (casting)	The outer shell (dense brick for insulation)
2.	Vacuum	Vacuum (coated with aluminum foil paper; this will help to radiate and direct secondary energy back to the kiln stacking area).
3.	Convection (through the cover or stopper)	Convection (through kiln door, chimney, and spy holes).
4.	Double glass shell	Tripple walls (In between the two brick walls is the recovery chamber, which is filled with sharp sand and ceramic shards. Chamber walls are coated with kaowool and ceramic fibers to reduce conduction).
5.	Chamber (silver coating to radiate heat in the flask).	Chamber (constructed with perforated bricks, incorporating thousands of tiny air pockets created by drilling directly into waste heat recovery chamber using PKS as pore agent).
6.	Spacers	Spacers and pillars (as support for kiln wall during heat treatment, expansion, and cooling process.

The table above outlines the similarities between the design of the thermos flask and the WHR chamber kiln.

Discussion of Findings

Various tests were performed using different energy sources such as gas – LPG, kerosene, diesel, and waste engine oil –WEO to determine the kiln's efficiency. One of the most important part of the use of fuel for firing was the combination of WEO and kerosene at sixty/forty percentage. The mixture when poured in an iron drum a boiled till it foamed, gave better firing outcome and combustion; but with the addition of petrol at five percent made the ignition in the firebox more effective. A significant amount of energy was saved during primary combustion. The extended period of heat after firing and rapid cooling post-fire was one of the most important findings in the evidence. The recent knowledge about Waste Heat Recovery (WHR) from kiln chambers, chimneys, and flues is expected to improve kilns and eventually satisfy the requirements for secondary energy sources. Focusing on recovering waste heat, therefore, represents a path that will help to promote energy efficiency in ceramics-processing industries, and similar pottery enterprises such as studio potteries in Nigeria because it captures some important amount of the energy expended in the firing of ceramic wares. The study has raised awareness among practitioners and policymakers about the impact of waste heat on the environment and its potential for eco-friendly utilization. It has addressed issues of primary energy consumption and has enhanced efficiency through the construction of a heat recovery chamber for secondary energy utilization.

Conclusion

An often overlooked aspect of firing ceramic work is the cooling of the kiln. The surface, color, and integrity of the work are all influenced by the rate at which the kiln is cooled. Rapid cooling can have various effects on wares in the kiln, such as thermal shock, thermal expansion and contraction, and glaze faults (including daunting, peeling, shivering, cracking, and pinholes). Daunting faults can occur during firing due to thermally induced stress as a result of cooling wares too quickly past the temperature at which silica undergoes a shift in the crystalline structure. Stress in an object is typically caused by a rapid change in temperature, with thermal expansion representing the amount of change in volume in response to a change in temperature. All glazes may benefit from a hold or soak at peak firing temperatures to correct glaze flaws and faults.

Different machinery and equipment consume varying amounts of energy and produce different waste heat quantities and qualities. To harness the potential of waste heat, it is crucial to examine and analyze the industrial processes used in large energy-consuming industries and explore suitable waste heat recovery methods that can be applied to small and medium-scale ceramic sectors (Jouhara et al., 2018). Numerous waste heat recovery technologies have been investigated and introduced to capture waste heat from the kiln and utilize recovery technologies for this purpose. These systems mainly consist of a common waste heat recovery system, all operating based on the principle of capturing, recovering, and exchanging heat with potential energy content in mind.

One recent example is in ceramics production, as discussed in the study shows that energy is an integral part of the process, used to fire kilns to create ceramic wares from clay products. Handling the process can be energy intensive, and inefficient energy usage can lead to waste, additional costs, and a higher carbon footprint. As an example industrial application, WHRC, or waste heat recovery chamber, is inspired by thermos flask technology and demonstrates the reciprocal relationship that industrial applications can have with energy-efficient designs and ingenuity, emphasizing the interdependence of energy conservation and maintainable industrial operations. In conclusion, energy is essential in every industrial application to ensure its performance in operational efficiency, economic viability, sustainable development, and innovation, thus serving as a foundation for the industrial sector.

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