FABRICATION OF PROTOTYPE MOBILE GAS KILN FROM LOCAL RESOURCES

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Abstract
Kiln design and construction has become a common activity among Nigerian Ceramists. As a result of the high cost of imported Kilns, many researchers in Kiln design and construction have emerged over the years. Some of them have perfected in it, especially in the construction of gas fired kilns. However, an aspect that seems to be lacking is the fabrication of light weight kilns, such that can be moved around, within or outside the studio, without recourse to folk-lift or crane. It is evident that the present locally fabricated gas kilns are too heavy to be moved about (even those meant to serve as test kilns) without the aid of crane or folk-lift. This paper is an attempt to develop a mobile gas kiln using indigenous materials. The fabrication involves the use of critically formulated light weight insulating bricks and a device that enables it to be pushed around. It consists of detachable chimney and burner pots. Detaching the two components reduces the weight of the kiln making it easier to be moved out of the studio to elsewhere and returned after use.

Introduction
The tradition of kiln fabrication using local resources has come of age in Nigeria. In early 1980s the high cost of imported kilns prompted many Nigerian ceramists to look inward for the fabrication of kilns using materials sourced from the local environment. The result is the proliferation of experts in kiln design and construction, among who are Chris Echeta, Umaru Aliyu, Levi Yakubu, James Ewule, Uzzi Festus, Ude Godwin, Emoda, C.S and Caius Onu. Their effort has led to the availability of kilns, particularly the gas powered types thereby helping to sustain ceramics development in Nigeria. However, an area that needs to be exploited is the development of light weight kilns. Most of the kilns produced in Nigeria are too heavy to be moved about, even those that are expected to serve as test kilns. This is part of the problems why ceramics training in rural areas where there is no nearby ceramics centre or studio has been very difficult. Because of non-availability of kiln at the training venue, the aspect of practical kiln firing is never taught. Consequently, such workshops were restricted to the production of green wares which were allowed to waste away after the training. If not because of the weight of kiln it would have been possible to move it to the venue of the training for the purpose of demonstration, so that the participants can be exposed to the practical modern techniques of firing. This paper therefore, discusses an attempt to fabricate a light weight kiln that can serve as demonstration kiln during ceramics workshops in rural areas where there is no pottery centre for such purpose.

Bricks Production
The term brick simply means small units of building material often made from fired clay. It is a fired clay block for building. Bricks are generally used for the construction of kilns, furnaces, crucibles (a heat-resistant container for melting ores), etc. This is because of their characteristics which include heat retention, corrosion resistance and refractoriness.

An essential aspect of kiln design and construction is the identification and selection of the right type of bricks for the desired results. Some important factors in bricks selection are refractoriness and insulation. The discovery of insulating bricks is one of the important improvements in bricks making. The development of insulating bricks (light weight bricks) has expanded the range of temperatures possible in kiln design and firing. This has also led to the fabrication of portable kilns (light weight kilns) that can be moved from place to place using heavy truck. The use of insulating bricks has made it possible for kilns produced abroad to be easily lifted and imported into Nigeria. It then means that the lighter the bricks the more insulating and portable the kiln will be. In this work, the bricks were not only insulating but sufficiently light to enhance mobility of the kiln.

In ceramics, bricks are classified into two main categories: refractory bricks and insulating refractory bricks. Ali (2013) states that refractory bricks refer to dense and heavy weight bricks while insulating refractory bricks refer to bricks that are made primarily from refractory fire clays and kaolin, formulated in such a way that the finished product is considerably porous.

The major raw material for bricks production is clay. Clay according to Rhodes (1973) is the "product of the geologic weathering of the surface of the earth, and since this weathering process is continuous and goes on every where it is an extremely common and abundant material in nature". According to Ali (2013) virtually all the clays insulate and resist heat to certain degrees. Ali notes that primary clay or Kaolin ($Al_2O_3.SiO_2.2H_2O$) is an excellent material for brick making because of its refractory nature. Shaw (1972) says that a material can be described as refractory if it can stand up to the action of corrosive solids, liquids, or gases at high temperatures. A clay body may consist of clay in its natural state, but according to Speight and Toki (2004) "clay body usually refers to a combination of materials formulated for a specific purpose. Fireclay is good clay for the manufacture of bricks. According to Fournier (2000) and Hammer and Homer (2004) in Ali (2013) fire clay is a general name for all secondary or sedimentary clays usually associated with coal measures or seams. The bricks manufactured from fire clay are called firebricks. Hammer and Homer (2004) and Fournier (2000) also say that fire clays are refractory clays with melting point that ranges from 1300^0C to 1750^0C. Some fire clays are as refractory as China clay and are able to withstand 1750^0C without deformation and probably melt around 1800^0C (Ali, 2013).

According to Peters (2006) a body or clay is well fired when it has been fired to its maximum degree of vitrification without deformation or has been fired to a temperature which has enabled the body to develop a sufficient co-efficient of contraction. This is to achieve a high vitrification point as a property of refractory bricks for more lasting and heat resisting functions. Vitrification and porosity' in this case refer to the range of water retention of the body and water absorption after firing. The vitrified body is one that has been fired to the extent of its being non-porous, or nearly so. The porosity of a body generally decreases as it is fired to higher temperature.

Low temperature (feasible or low refractory) clays, that is, those that "will not withstand high temperatures but breaks down with heat and melt before 1300^0c, can be used particularly when building low temperature Kiln (Bhatia, 2012)". Rhodes (1968) in Ali (2013) states that "an ordinary red brick, which is usually fired to about 1000^0C, will withstand perhaps 1100^0C without melting, bloating or deforming"; after all, "early kilns were commonly built of red bricks and these were entirely satisfactory for low-temperature firings".

Cardew (2002) states that the bricks must not only be able to stand the temperature but must also be reasonably immune from spalling (the tendency to break away in flakes on the face, at the edges or at the corners). Spalling is a special case of poor thermal shock resistance and is usually due to too much free silica in the bricks or where the texture is too fine. The bricks will therefore have to be well grogged. Grog (ground bisque) can be added to dense refractory bricks to enhance their quality of density and hardness.

The bricks used to produce the kiln were made of fire clay sourced from Enugu and sawdust, one of the abundant resources in timber sheds or wood mills. Effort was made to ensure that the bricks assume a high degree of lightness necessary for optimum production. These local materials (clay and sawdust) were subjected to critical processing and analysis necessary to achieve the desired results as discussed later.

According to UNEP (2006), one of the desirable features of insulating bricks is the low thermal conductivity, which usually results from a high degree of porosity structure of air. Insulating bricks consists of minute pores filled with air which have in them very low thermal conductivity. The air spaces inside the brick prevent the heat from being conducted but the solid particles of which the brick is made conduct the heat. So in order to have required insulating property in a brick, a balance has to be created between the proportion of its solid particle and air spaces. The thermal conductivity is lower if the volume of air space is larger (Bhatia, 2012). However, the thermal conductivity of a brick does not so much depend on the size of pores but on the uniformity of size and even distribution of these pores. Hence uniformly small sized pores distributed evenly in the whole body of the insulating brick are preferred (UNEP, 2006).

The high porosity of the brick is created during manufacturing by adding to the mix fine organic materials, which may include among others, rice husk, seed shells, grains of guinea corn and sawdust. During firing, the organic addition burns out, creating internal pores. According to Bhatia (2012) other ways to accomplish high porosity, include the use of;

1. materials which expands and open up on heating.
2. volatile compound like naphthalene
3. aluminum Al powder in combination with NaOH solution called chemical bloating.
4. substance which by themselves have open texture e.g. insulating bricks; grog, vermiculite, ex-foliated mica raw diatomite
5. foaming agents added to slip, etc

The sawdust or wood dust used to accomplish the required porosity in bricks produced was sourced from timber shed in Nsukka area of Enugu state. These are fine particles that are created when wood is cut with a saw, because the saw creates a path by removing wood. It can range from dust size to clumpy grains. Fine sawdust can also be created by sanding wood. Sawdust is a combustible material that can easily be burnt off during firing and when mixed with clay, it is very ideal for the production of insulating bricks.

Oyeoku (1988) and Ogbu (2005) have documented the results of the chemical and physical analysis of fire clay samples from Ngwo in Enugu as shown in Table 1. The results show that fireclay from Enugu is ideal for the production of insulating and refractory bricks, because of their high content of silica and aluminum oxide which are very refractory. The researcher, therefore, relied on the use of fire clay from Ngwo in Enugu. The fire clay was excavated from the deposits in Ugwu Onyeama hill near former location of PRODA, in Ngwo Local Government Area of Enugu State. The excavation was done with implements, bagged and transported to the studio at the Department of Fine and Applied Arts, University of Nigeria, Nsukka.

Processing the Materials: Because of the rocky nature of the clay, the researcher first broke them with hammer. Then crushed them with mortar and pestle to coarse particles. It was finally grounded with grain grinding machine and sieved with the aid of plastic sieve to extract the finer particles of the clay.

Preparation of the Body: The fire clay and sawdust which formed the raw materials used, were measured using a plastic container of $50cm^3$. The progression method was used to determine a satisfactory mixture (recipe). After series of test samples, the following recipe was found satisfactory.
Sawdust – 60 per cent
Clay – 40 per cent
Firing – 1200^0C

Though fragile but very light
The materials were thoroughly mixed together (dry mixing) in the basin using the shovel. Water was added gradually and further mixing continued using the shovel until the desired consistency was obtained. The mixed batch was covered with a polythene sheet to prevent air from penetrating and also to facilitate the aging process (fermentation period of the batch). The aging period took 5-10 days before the desired texture was achieved. After aging, the batch was ready for brick moulding.

Brick Moulding and Firing: Before the brick moulding process commenced, the mold was fabricated using wood. The usual dimension of the brick mold is as described by Rhodes (1968), but because the kiln to be produced is a prototype, instead of 9 x 4½ x 2½ inches, 5 x 2½ x 1 was used.

The bricks were made by applying separator on the wooden mould before filling it with the mixture. The top of the layer was smoothened using flat object before pressing it with a heavy flat stick or wood to attain the desired level. The bricks produced were left for a period of 5 days to dry after which they were lifted up, turned sideways or up-side-down for complete drying (fig 3). The bricks were given proper attention during drying to avoid cracking or warping.

After drying, the bricks were ready for firing. The bricks were fired to a temperature of about 1200^0C. The sawdust burnt off and the combustible products were expelled from the refractory body mass, resulting in a compact light product having the desired porous structure. According to Chester (1973), the range of any refractory brick is determined by its maximum service temperature. For instance, if a ceramics ware is to be fired to 700^0C to reach maturity, the brick has to be fired to a temperature of between 700-1200^0C to exceed that of the ware's temperature.

Kiln Design and Construction

The steps below were followed in constructing the kiln.

1. Kiln design
2. Fabrication of metal framework
3. Bricklaying
4. Test Firing

1. Kiln Design

This involves the development of the kiln plan or working drawing which outlines the size of the kiln, its parts and their relationships (Fig 5). In developing the plan, serious consideration was given to the principles or rules and regulations governing efficiency in kiln design and construction. Rhodes (1968) identified some of these principles. According to him,

> The best general shape for a kiln is something approaching a cube…, kilns are built in rectilinear shapes mostly for convenience in planning and construction, but the cylindrical shape with a dome is perhaps a better shape for the circulation of heat. A kiln of 10 cubic feet is usually fitted with four gas burners, and one of 25 to 40 cubic feet with six. More burners give a better distribution of heat. Space must be provided for combustion. In case of a gas, each burner needs an area of about 500 cubic inches.

Leach (1948) in Rhodes (1968) also "recommends that the chimney diameter be ¼ to 1/5 the diameter of the kiln. That would make the chimney for a 10 foot kiln at least 2feet in diameter and a maximum of 2 ½ feet". As suggested by Leach, the height of the chimney must be at least 25 times its diameter. Even though some of these rules propagated by the early kiln researchers, have been challenged, they still form the basis for efficiency in kiln design and construction. Therefore, the plan of kiln was actually guided by the documented experiences of successful Kiln designers. Figure 5 illustrates the kiln plan showing the relationships of the various parts.

2. Fabrication of the metal framework

Iron of 25mm angle was used in the construction of the kiln frame. The kiln was designed in such a way that it has three coaches that can be connected or disconnected, such as the pedestal, chamber and the chimney; even the fire box is also detachable for easy movement of the kiln.

3. Bricklaying

Bricks were laid so that the joints were above each other. Just as in normal house building where each course over lays the next. This is also true of a double wall. Brick walls are laid in alternating patterns so that joints are broken and the layers tied together. As shown in the kiln plan, insulating bricks were used for both the outer and inner lining. This was done to ensure weight reduction because the use of dense refractory bricks for outer or inner lining is responsible for the weight of the kiln. Most imported electric kilns are linned with ceramic fibre for the purpose of weight reduction. As part of the effort to reduce the weight of the kiln, the chimney was not built with bricks but left as metal casing (Fig.9).

Conclusion

The paper clearly reveals that locally sourced materials can be successfully used to formulate light weight bricks for light weight kiln construction by subjecting them to critical studio processes involving the use of hammer, mortar, pestle and grain grinding machine in place of jaw crushers and other industrial machines. From the result of the experiments, sawdust and fire clay have proved to be good materials for light weight bricks production. The use of the ratio of 40% clay and 60% sawdust instead of the usual 60% clay and 40% sawdust proved successful for the production of an improved light weight bricks. The paper has also shown that these bricks can be harnessed and used to enhance portability in kiln design and construction. In fact the paper has demonstrated the possibility of fabricating light weight gas kiln that can be moved with ease from place to place using materials sourced from the local environment. With this attempt it is possible to fabricate kilns that can be moved and used as resource equipment during workshops organized in rural settings.

Table 1: Chemical Analysis of Ngwo Fireclay

Silica (SiO_2)	Alumina (Al_2O_3)	Ferric Oxide (Fe_2O_3)	Titanic Oxide (TiO_2)	Calcium oxide (CaO)	Magnesia (MgO)	Potash (K_2O)	Soda (Na_2O)
57.32	22.08	5.70	0.33	0.47	0.23	0.66	0.10

Source: Oyeoku (1988)

Table 2: Physical Analysis of Ngwo Fireclay

% Drying shrinkage	%Making moisture	Green strength Kgf/Cm^2	Plasticity Ratio	Firing temp.	% Fired shrinkage	% Total shrinkage	Fired strength	% App. Porosity	% Water Absorption
8.60	20.80	29.70	2.81	1300	0.44	9.04	346.70	25.30	11.90

Source: Nigerian coal corporation information manual as quoted in Ogbu (2005)

Fig. 1a: Fireclay deposit at Ngwo in Enugu State (Site I)

Fig. 1b: Fireclay deposit at Ngwo in Enugu State (Site II)

Fig. 2a: Fireclay excavated from the deposits Site I

Fig. 2b: Fireclay excavated from the deposits Site II

Fig. 3: Molding the bricks

Fig. 4: Molded bricks drying gradually

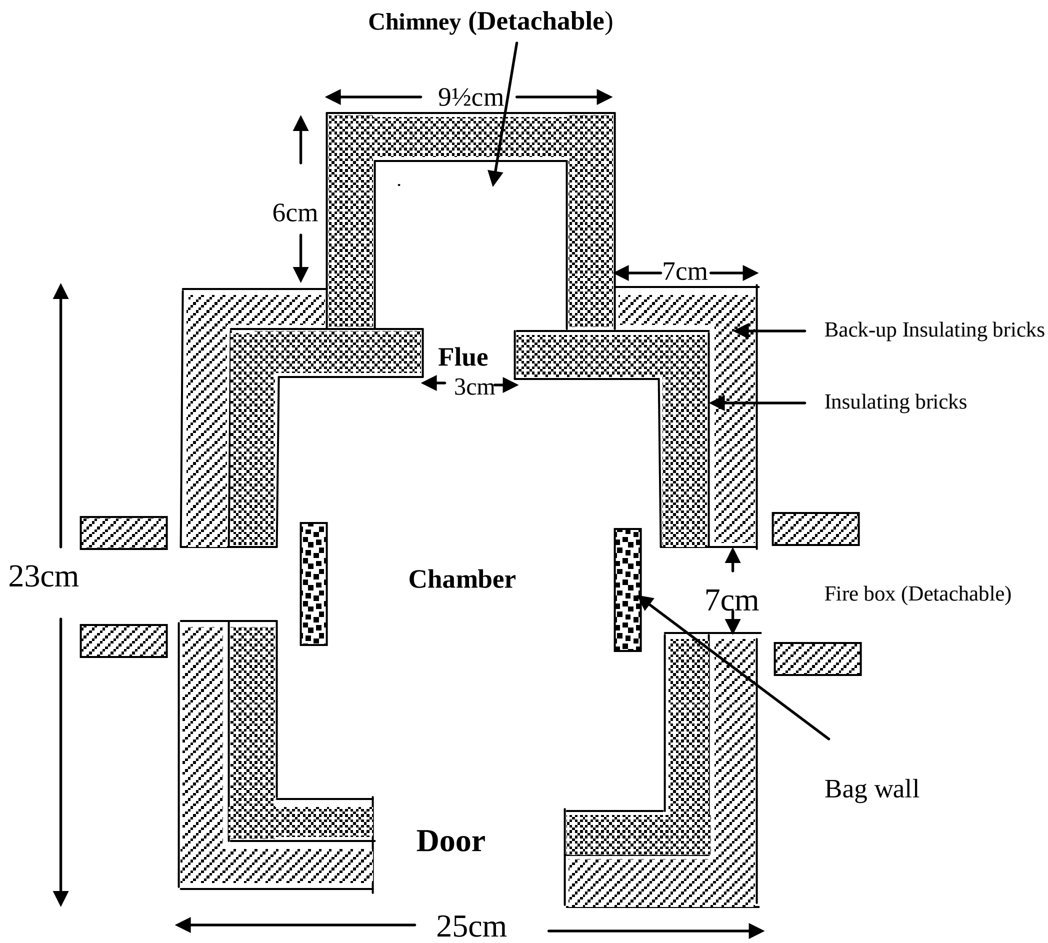

Fig. 5: Kiln plan and dimensions

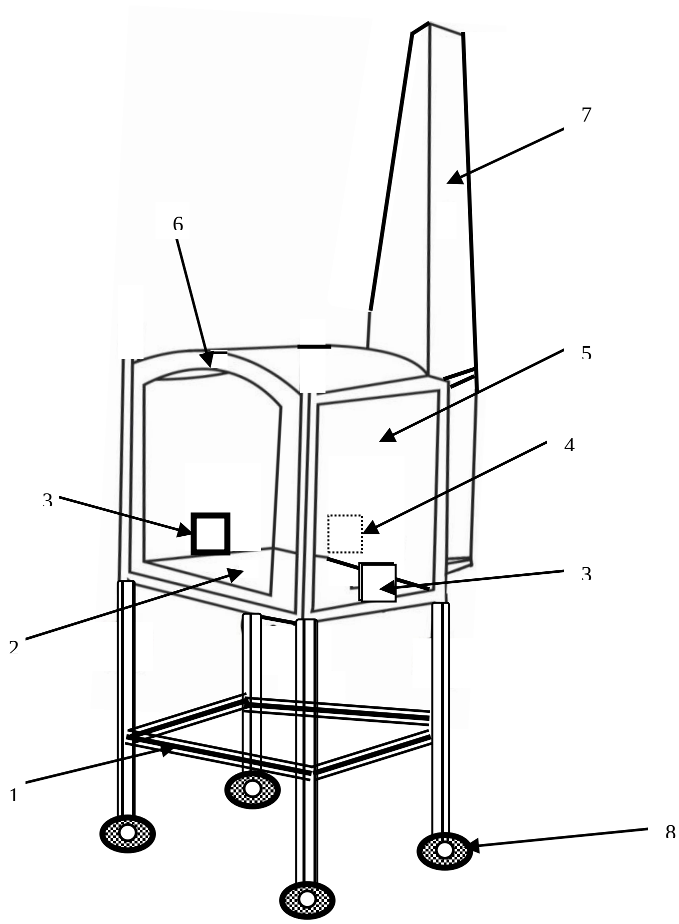

Fig. 6: The Metal Framework

The sketch parts are described below:

1. The stand 2. The floor 3. The fire box 4. The flue box 5. The wall
6. The arches or crown 7. The chimney 8. The wheel

The Stand: This is a detachable pedestal on which the kiln stands. It was constructed with angle iron of 2mm thick.
The Floor: This is the floor of the kiln or base of the chimney.
The Fire Box: This is where the burner is inserted during firing.
The Flue Box: This is the passage for hot air, flames and fumes from the kiln chamber to the chimney.
The Wall: This is a double brick wall firmly linked together from the inside course to the outside.
The Arches: These are wooden formers used to construct the arch or roof of the kiln.
The Chimney: This is a tunnel made of detachable metal through which the fumes escape from the kiln chamber to the atmosphere.
The Wheels: These are hard tubeless tyres that enable the kiln to be moved around.

Fig. 7: Iron work in progress

Fig. 8: Detachable pedestal fitted with tyres

Fig. 9: Detachable chimney

Fig. 10: Cutting the bricks

Fig. 11: Constructing the kiln


Fig. 12: Back view without the chimney


Fig. 13: The completed kiln


Fig. 14: Test firing the kiln

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