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Design and Fabrication of Gas Kiln Using Local Materials Sources

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ABSTRACT

The dynamic roles of small scale ceramic industry in developing and promoting rapid industrialization are very critical and the success of ceramic artist depends greatly on how to fire ceramic wares. One of such equipment needed for successful business is kiln. Kiln machines are used to fire or heat ceramic products. However, in Ghana most kilns either electric or gas are imported thereby making the cost of kilns very expensive. Majority of potters rely on firewood kilns to heat ceramic products, resulting in smoke that causes environmental pollution. To ensure constant firing of ceramic products and reduce the rate at which trees are felled and used as fuel for firewood kilns, the study's adoption of an effective gas kiln is very necessary especially, by using local materials. The use of efficient gas kiln would greatly improve production rates of ceramic products and comparatively reduce the periods of firing in firewood kilns. The main objective of this study was to design and fabricate gas kiln machine so as to optimize its efficiency at low cost, reduce total time of firing ceramic wares in firewood kilns and produce quality fired pieces. The design of the gas kiln was achieved through proper focus on the materials and other design criteria for various component parts. The materials used to compose the refractory bricks were: Abonko clay 60%, Kaolin 25%, Bakakyire clay 10%, Sawdust 3.5%, and droplets of Sodium Silicate 1.5%. The gas kiln consisted of inner chamber, the main frame and gas transmitting valves. The results of the newly fabricated gas kiln machine shows that maintenance cost is cheap; firing time of wares is reduced and free from smoke. The gas kiln is therefore recommended for firing ceramic products.

Keywords**:** Clay, Design And Fabricate, Firing, Gas Kiln, Local Materials.

1. Introduction

1.1 Historical development of kilns and firing techniques

According to Chavarria (1993), the process of firing ceramic wares such as pottery is an ancient one. When people first learned to control fire, which it was used to cook food and to keep it warm, they

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observed that the clay pots they had made became harder when exposed to the flames. This system of firing, which is still practised in other parts of Africa, may well have been the starting point of converting fragile clay into durable ceramic material (Chavarria, 1993). Peterson and Peterson (2003) also posit that one of the most primitive, simple, and universal of all firing methods is the pit firing. It demands only a place where a hole can be dug in the ground, and twigs or other combustible material to create the fire. This method of firing is also referred to as open pit firing which is still used in most pottery villages in Ghana. It has the merits of acquiring no permanent structure of any kind, so a firing could be done anywhere and with readily source of fuel. The increase of heat is however limited as the open nature of the fire permits heat to rise without obstruction. Firing temperature is not enough to heat hard impervious pottery or to melt glazes (Oteng, 2011). In the pit firing, the pots were often subjected to direct impingement of the flame and so were discolored by dark and black spots. Careful control of the fire could however produce a clear, smoke-free atmosphere resulting in well oxidized pottery (Rhodes, 1968).

It can be stated that much time has passed between the simple bonfire and the kilns of today, but in spite of some variations, the basic process of firing remains the same. This goes to emphasize that, a kiln is important equipment in the production of ceramics. This is because an unfired clay ware is fragile and has the tendency of cracking easily.

In describing a kiln, Peterson and Peterson (2003) ascertain that although modern kilns are different from the primitive type, the kiln still is simply a container of varying dimensions in which pieces of ceramic products are placed, retained heat and made it possible to introduce a gradual or rapid increase of temperature in order to fire these pieces. Oteng (2011) quotes Leach (1960) said "a kiln may be considered simply as chambers fed with flames by one or more fire places and from which a chimney draws heat and smoke". A kiln may also be described as a box of refractory materials which accumulates and retains heat directed into it. Glenn (1971) describes a kiln as an oven or furnace capable of holding hot fires and maintaining the heat necessary to drive nearly all moisture out of something heated in its interior.

1.2 Types of kilns

There are various types of kilns in the ceramic industry. Such kilns can be classified into types based on its shape, design and on the source of fuel used for its firing. Based on the type of fuel used to power kilns, there are five major types of kilns which are available. These are coal, oil, electricity, firewood and gas.

(i) Coal burning kilns: In Ghana, the coal-fired kiln is scarcely seen in potters' workshop. From about 1700, however, it was very popular in European Ceramic Factories because coal, which is highly combustible, was at that time a plentiful and cheap fuel (Chavarria 1993). However, just as with oil, the combustion of coal produces impurities (such as sulphur and ash deposits). That can attack glazes if the pots are not protected in refractory containers. In Ghana, the use of coal as fuel is practically inappropriate since this type of fuel is unavailable. It can also prove a costly nuisance. Gregory (1977) also notes that, as a fuel for large kilns, its storage space, inevitable dirt and expense, rather puts it to the bottom of the fuel list for practical reasons.

(ii) Oil fired kilns: The fuel combustion of oiled-fired kilns is complicated, and because of the vast quantities of fumes they give off, such ovens are not suitable for installation in large towns that have regulations on smoke pollution (Chavarria 1993). Oil firing kilns are known to be effective and very cheap. The atmosphere can be easily controlled and every rapid advance of heat is possible if desired. The cost of fuel is not excessive and firing atmosphere can be controlled from oxidation to reduction. Despite these qualities and its availability, oil has not been popular in the ceramic industry in Ghana. This is because its demerits far outweigh the merits. Nelson (2002) states oil is a satisfactory fuel, but it has some draw backs. A large amount of space must be left for the flames, since the fumes that are given off, together with the noise blowers, make an oil-burning kiln impractical for use inside the potter's studio, especially small scale industry.

(iii) Electric kilns: The electric kiln is supported by a metallic framework containing refractory bricks that, on the outside, are metal-plated (Chavarria, 1993). It works on the principle of where electric current is run to resistance elements to generate radiant heat in the kiln. The insulation materials used for the walls impede the transfer of heat to the outside and permits the temperature inside the kiln to approach that of the heating elements. It is easy to operate by flicking a switch; no special skills or knowledge is required to fire, allows the operator to concentrate on other things. In addition, Nelson (2002) mentions that electric kiln firing tends to be uniform with very little variation in results and needs no chimney or fuel lines. In spite of the numerous merits, the electric kilns have some drawbacks. One major demerit of the electric kiln is cost. The cost of electricity is comparative higher in relation to other fuels. Firing with electricity usually costs twice as much as firing with oil or gas (Oteng, 2011).

(iv) Firewood kilns: A wood fired kiln that is designed to correct specifications and constructed with the right type of materials and has a good operating system, can fire adequately to give good results. According to Oteng (2011), "Norksa (1987) holds the view that firewood is easily capable of heating kilns beyond 1300 °C if desired and it also produces long flames which help to even out temperature inside the kiln". Nelson (2002) contends that firewood is highly ranked as fuel for pottery because of the wonderful surface effects realized in wood fired kilns. As quoted by Oteng (2011), this assertion is supported by Speight & Toki (1999) that firewood kiln could achieve effects that would be impossible to get in any other way. However, one drawback in the use of firewood is the inevitable production of smoke which can be disturbing to neighbors. Therefore, firewood kilns need to be located in an isolated environment, with a well ventilated shed, standing by itself and with its separate chimney.

(v) Gas kilns: Gas kilns are built with a metallic outer casting around refractory bricks, which are light in the walls and heavy in the base. Unlike oil burners, gas burners are simple, inexpensive and fool proof. Again, Oteng (2011) quotes Norton (1956) indicates that gas kilns can achieve very high temperatures. According to him, well-designed kilns give uniform temperature and may be used up to 1450 °C (cone 16). They are built both for side and top loading. The latter permits the attainment of uniform temperature with greater ease. Gas kilns are also reported to produce interesting accidental effects and variation of colours and textures. These effects make the pots fired in them very unique. Also, the installation and maintenance of gas kiln is relatively cheap, and the firing times and consequent fuel costs are often considerably less than the expenses incurred when using electric kiln (Chavarria, 1993).

For the purpose of this study, gas kiln is deemed to be the most suitable and easiest way of firing ceramic products in small scale ceramic industry, more especially as part of Ghana's energy policy which aims at reducing the pressure on electricity and fuel wood due to the discovery and commercial production of crude oil in recent time. The government is educating and promoting domestic and industrial use of Liquefied Petroleum Gas (L.P.G). As a result, the use of L.P.G is gaining popularity of late for both domestic and industrial use in Ghana; essentially, with the Gas Processing Plant in Atuobo in the Western Region, both the private companies and government agencies are engaged in the distribution of gas as a source of fuel to various parts of the country.

1.3 Statement of the problem

The use of fire wood kiln normally restricts ceramic artists to only bisque fired works. This does not auger well for the small scale ceramic industry. It is against this backdrop that the study seeks to design and fabricate kiln machine by using local materials to help ceramic artists to adopt the use of the proposed efficient gas kiln that would greatly improve production rates of ceramic products and comparatively reduce the periods of firing in firewood kilns. Again, the researchers deem it necessary to design and produce a larger gas kiln (updraft) that can perform gloss firing of ceramics wares as compared with firewood kiln.

1.4 Objective of the study

To design and fabricate gas kiln for firing and glazing of ceramic wares.

1.5 Research question

To what extent can local materials be used to produce burnt refractory bricks and mortar for fabrication of gas kiln?

1.6 Delimitation

The fabricated kiln would only use gas as a source of fuel.

1.7 Limitation

The study was limited to the construction of permanent chimney for the gas kiln due to its non-permanent position. However, that did not affect the success and efficacy of the kiln.

1.8 Importance of the study

1. The study will assist potters and ceramic artists to fabricate their own gas kilns when they establish their own small scale ceramic industries.

2. It will also reduce over dependency on wood as a source of fuel for firewood kiln.

2. Materials and methods

2.1 Methodology

Descriptive and experimental research methods based on qualitative and quantitative research approaches were employed. The Descriptive method of research is essential because different kilns existing at various institutions and industries had to be looked at, described and analyzed before coming out with a design and fabrication of the gas kiln that would in the long run solve problems existing kilns could not. This method was also adopted to describe the various materials, tools and equipment used in the study. Moreover, it was used to describe the design and production processes and the appreciation of the results. The experimental research method was employed to identify the suitability of materials, available tools and equipment used in the study (Best, 1981). Experiments were conducted to find out the suitability of the use of Abonko clay, Bakakyire clay, Kaolin and sodium silicate (slip) to compose clay bodies for the production of the refractory bricks as well as the refractory mortar. Experiments were also conducted to look at the relevant and suitable method of cutting out the galvanized sheet to the required measurements. The quantitative approach was adopted to assist in calculating quantities of refractory bricks and mortar needed for lining the fabricated kiln.

2.2 Selection of materials, tools, equipment and description of the component parts

Some of the materials used for the fabrication of the gas kiln included;

1. Angle Iron- It is a type of metal pole or bar bent at an angle along its long dimension used for supporting a structural framework .They were designed in a way that they could put a support at the base of a heavy object from collapsing.

2. Red oxide paint - This is a red liquid paint which was used in painting the metallic parts of the fabricated gas kiln.

3. Metal plate - They are metallic sheets used for framing the outer layer of the kiln.

4. Refractory bricks - special bricks made from the composition of Abonko clay, Bakakyire clay, kaolin, sodium silicate and saw dust which were used in laying the inside or inner part of the kiln.

5. Fibre glass- It is a material which is used in padding the structure of the kiln before the refractory bricks were laid.

6. Saw dust - It is a material used in mixing the composition to produce the refractory bricks.

7. Abonko clay – it was used in mixing the composition to produce the refractory bricks.

Plate 1: Angle iron

Plate 2: Red oxide paint

Plate 3: Metal sheet

Plate 4: Refractory bricks

Plate 5: Fibre glass

Plate 6: Saw dust.

Plate 7: Abonko clay

Tools and equipment used for the fabrication of the gas kiln involved among other things;

1. Sand paper (Abrasive) - it was used to make the surfaces of the metal frame smooth before actual finishing of the kiln.

2. Measuring tape - it was used for measuring the length, thickness and width of the materials for the project. It was also used to measure the actual size of the kiln.

3. Grinding machine - the grinder was used in smothering the rough parts of the metal after welding.

4. Arc welding machine - it was used to weld the metal parts of the fabricated kiln together.

5. Hacksaw - the hacksaw was used to cut the metal before welding of the various parts together.

6. Wheel barrow - it was used to carry tools and materials from one place to another.

7. Hammer - it was used for hitting sharp pointed material into one another.

Plate 8: Sand paper

Plate 9: Measuring tape

Plate 10: Grinding machine

Plat 11: Arc welding machine

Plate 12: hacksaw

Plate 13.Wheel barrow

Plate 14. Hammer

2.3 Designing of the gas kiln

Several sketches were made until the appropriate one was selected and improved upon to achieve the final design. Samples of the sketches are shown below;

Plate 15: Inner view of the designed kiln.

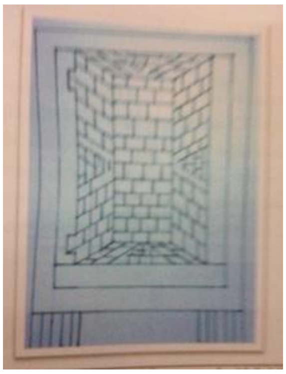

Plate 16: Inner part with arranged bricks.

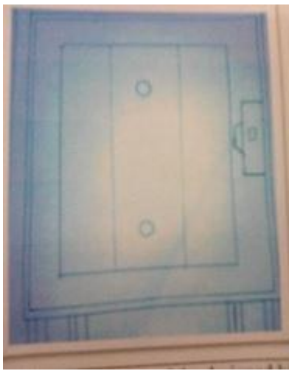

Plate 17: Frontal view of the designed kiln.

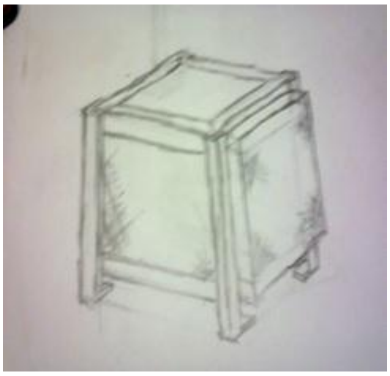

Plate 18: Final sketch of the designed gas kiln.

2.4 Preparations of materials

Experiments were conducted in various compositions until the required composition was attained for the production of the refractory bricks. The required materials were: Abonko clay 60%, Kaolin 25%, Bakakyire clay 10%, Sawdust 3.5%, and droplets of Sodium Silicate 1.5%. The materials were then gathered ready to be weighed and processed accordingly.

The rock-like kaolin from Sofo Krom was brought to the construction site and ground into fine powder and so was the Abonko clay. After processing the materials into powdered form, they were measured and mixed with water.

Plate 19: Digging of Kaolin.

Plate 20: Grinding of Kaolin.

2.5 Mixing of materials for manufacturing refractory bricks

A basin was filled with the weighed materials; Abonko clay 60%, Kaolin 25%, Bakakyire clay 10%, sawdust 3.5%, and droplets of sodium silicate and water was added to get the mixture to a fluid consistency, and were mixed thoroughly to a uniform consistency of clay body composition.

The composition was left to dry up to a stage that could be used to produce the bricks. A level and firm ground was prepared for the production of the bricks. After preparing the ground, the mould box was placed on the ground. The well mixed composition was then smashed into the mould box and pressed with the hand to take the shape of the mould and leveled with stick called strike. This process was repeated until adequate bricks were produced.

Plate 21: Initial mixing of the clay body composition.

Plate 22 (a) and Plate 22 (b): Pouring and mixing of the clay body composition.

Plate 23: Filling the mould box with ball of clay.

Plates 24: Pressing of ball of clay in the mould.

2.6 Drying of the bricks

Wet manufactured bricks were placed on a platform to dry and the surfaces were sprinkled with sand to prevent them from sticking onto the ground in the hot sun.

Plate 25: Wet manufactured bricks on platform to dry.

Plate 26: Dried bricks ready for firing.

The dried bricks were intermittently turned to ensure uniform drying and also to prevent the bricks from warping. This was also done to ensure that atmospheric moisture contained in the dried bricks had evaporated to avoid cracking during the drying process.

2.7 Firing of the bricks

The dried bricks were packed into a firewood kiln ready to be fired. The pre-heating, which was the gradual heating of the bricks, lasted for about four hours. This was to ensure that all the atmospheric moisture left after drying the bricks, had evaporated to avoid cracking in course of firing.

The firing temperature of the kiln was progressively increased for twenty four hours to ensure that the composed refractory bricks were well fired. The kiln was left to cool down for two days before the bricks were removed.


Plate 27: Firing of the bricks.


Plate 28: Samples of fired refractory bricks.

3. Results and discussions

It was realized that the manufactured fired refractory bricks were of good quality after carrying out the compressive strength of the brick at the Building Technology Laboratory of Takoradi Technical University. The average compressive strength of the refractory bricks had an average strength of 8.3N/mm^2 as shown from the table below.

Table 1: Strengths of bricks after firing

Bricks	Strength after firing (N/mm^2)
A	7.53
B	7.25
C	8.79
D	7.11
E	8.94
F	5.93
G	11.06
H	9.36
I	8.28
J	8.75
Average	8.30

The next step was the construction of the various metal components of the gas kiln. The angle irons were joined together to get the structure of the kiln. The angle iron was measured and cut with hacksaw. With the use of electrode, the measured angle iron bars were joined together to form the structure of the kiln measured as 0.96m × 1.135m × 1.24m; representing the breath, width, and height respectively.

The various sides were marked and cut out on the galvanized sheet to the required measurements. The cut galvanized sheets were welded to the structure to form an enclosed box. Holes through which the burners would pass were also marked and cut out (Finch, 2006).


Plate 29: Skeletal structure of the kiln


Plate 30: Passage of the burners


Plate 31: Welded galvanized sheet to the frame.

Plate 32: Complete structure of the kiln

Plate 33: Painting of the kiln

The complete structure of the kiln was now ready for painting. The framed gas kiln was painted with red oxide. The purpose of the painting was to prevent the galvanzed sheet from rusting and also to make the kiln very durable. After painting, the framed gas kiln was ready to be lined with the composed refractory materials.

3.1 Estimates for number of bricks and mortar required for laying of bricks in the kiln

Table 2: Estimating for refractory bricks

Volume of the Kiln	0.96m x 1.135m x 1.24m
	1.35m^3
Internal dimension (volume)	1m x 0.48m x 0.9m
	0.432m^3
Total volume of the bricks in the Kiln	1.35m^3 – 0.432m^3
	0.918m^3 ≈ 1m^3
Size of a brick	70mm x 120mm x 245mm
	0.07m x 0.12m x 0.245m
	0.002058m^3
Volume of brick with mortar (10mm thick)	80mm x 130mm x 255mm
	0.08m x 0.13m x 0.255m
	0.00265m^3
Number of Bricks	**1m^3/0.002058m^3**
	370.370
Add 5% wastage	5/100 × 370.370
	18.5185
Total bricks	370.370 +18.5185
	388.89 ≈ 389
Total bricks used	**389**

Table 3: Estimating for the Refractory Mortar

Mix Ratio (Anthill: Kaolin)	1: 6
Volume of 1 brick without mortar	0.07m x 0.12m x 0.245m
	0.002058m^3
Volume of 371 bricks without mortar	371 x 0.002058m^3
	0.7635m^3
Volume of bricks without mortar for 1m^3	0.7635m^3
Required amount of mortar	1m^3 – volume of bricks without mortar
	1 – 0.7635m^3
	0.2365m^3 (wet volume)
Dry volume of a mortar	Wet Volume x 33% Bulkage of Kaolin
	0.2365 x 1.33

	0. 314545m³
Anthill	0.314545 x 1/7 x 1440kg
	64.71kg/50kg
	1.29 bag of anthill (or Equivalent to 2 bags of cement)
Kaolin	0.314545 x 6/7
	0.2696m³
Therefore, for 1 cum of (0.07m x 0.12m x 0.245m) brickwork, it would require	389 number of bricks
	65kg of anthill (or equivalent to 2 bags of cement)
	0.270m³ of Kaolin

From the calculations, a total of 389 manufactured refractory bricks; and refractory mortar consisting of anthill and Kaolin with droplets of Sodium Silicate (approximately 1.5%) were used to lay the bricks inside the kiln.

In composing the refractory mortar, preliminary tests were conducted to ensure that the mortar withstand all destructive forces, thermal expansion, spalling, and slagging that the bricks withstand. This was to ensure that the composed mortar has similar chemical properties to the bricks, balanced in characteristics, in order to ensure a strong bond (Olsen, 2001). The inner parts the door and the kiln were padded with fibre glass to act as heat insulator before arranging the manufactured refractory bricks, with the composed refractory mortar as binding agent to join the bricks. The process was repeated until it was fully built with the required refractory bricks and refractory mortar joints.

During arrangement of refractory bricks in the kiln, it was needful to put on mask to prevent inhalation of dust and other particles.


Plate 34: Digging of Anthill


Plate 35: Mixing of Kaolin and Anthill


Plate 36: Lining the inside of the door with fibre


Plate 37: Lining the inner walls with fibre glass.


Plate 38: Arrangement of refractory bricks in the kiln

3.2 Construction of arch of the kiln

Brett (1994) states that arches are constructed in brickwork and may be flat, segmented, or semicircular in shape. For the purpose of constructing this kiln, the semicircular in shape was adopted. The arch of the kiln was shaped by the use of curved bricks and its purpose was to allow better circulation of heat within the kiln. The shape and construction of the centre was governed by the shape and size of the arch to be constructed. The type of laggings used depended on the size of the arch bricks with refractory mortar joints required. In setting out the arch centre, thus, semi-circular curve, trammel which was in a form of compass was used to strike the semi-circle.

Plate 39: Making the arch of the kiln.

Plate 40: The improvised chimney.

The outlet of the chimney was built at the back of kiln to allow excess heat to escape through the chimney. The heat from the gas burners would travel horizontally before rising full circle around the chamber to fire the wares, down again, and out through a damper hole at the back of the kiln.

It must be stated that in constructing the gas kiln, environmental factors were also considered to ensure that these factors would not affect the quality of the kiln. For instance, the construction was carried out under normal room temperatures to prevent the metal sheet from over-expansion; low humidity to ensure that the quality of mixed mortar for joining was not compromised, and also to prevent water vapour from soaking the fibre glass and refractory bricks which could result in any unwanted reactions.

3.3 Finishing and testing of the fabricated kiln

Finally, the inner part of the kiln was smoothened with knife and sandpaper to ensure that it would not be harmful or injurious to human beings during packing of wares in the kiln. The kiln was tested by undertaking bisque firing and satisfactory result was achieved. It was later on used to conduct glost firing and the glazed wares came out successfully. It was also realized that the gas fuel used was very efficient and economical for the fabricated gas kiln.

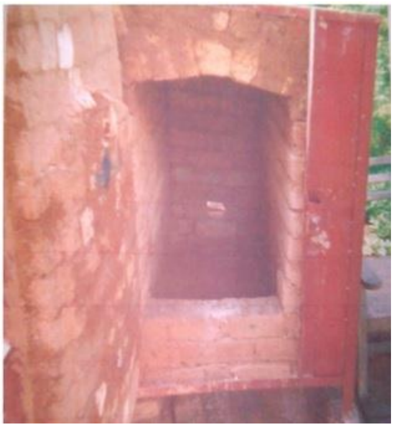

Plate 41: The inner part of the fabricated gas kiln

Plate 42: Fabricated gas kiln after testing

Plate 43: The fabricated gas kiln

It must be added that precautionary measures were taken during firing to prevent leakage of gas; and also the kiln was mounted in an airy building or shed to circulate the excess heat that would come out from the chimney in order not to make the gas kiln room hot.

4. Conclusions and Recommendation

4.1 Conclusions

The major finding from the fabricated gas kiln was that it had been tested and satisfactory result was attained. The refractory bricks produced from local raw materials were capable of retaining heat, the composed refractory mortar was able to join the bricks successfully thereby serving as good binding agent, and so could be embarked on as mass production for sale to potters and ceramic artists, who would like to fabricate their own gas kilns.

4.2 Recommendation

It is therefore recommended that young ceramic graduates, potters and ceramic artists should be encouraged to have some skills in this systematic approach of fabricating efficient gas kiln to enable them go into small scale ceramic production, so as to bring desired increases in ceramic products in Ghana.

The researchers intend to partner other agencies to seek financial support to embark on mass production by training more artisans in order to provide employment in rural areas and to improve quality of ceramic products.

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