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Design and Fabrication of Gas Kiln from Local Raw Materials in South Eastern Nigeria.

Osonwa Nobert Okechinyere , Odewale Isiaka Olajide, Arihilam E.C, Mbabuike Ikenna U, Izuegbu Lilian C, Ekwueme Ekenna

Department of Ceramic and Glass Technology, Akanu Ibiam Federal Polytechnic Unwana, Afikpo Ebonyi State Nigeria
Department of Ceramic and Glass Technology, Akanu Ibiam Federal Polytechnic Unwana, Afikpo Ebonyi State Nigeria
Department of Electrical and Electronics Engineering, Akanu Ibiam Federal Polytechnic Unwana, Afikpo Ebonyi State Nigeria
Department of Mechatronics Engineering, Akanu Ibiam Federal Polytechnic Unwana, Afikpo Ebonyi State Nigeria.
Department of Metallurgical Engineering, Akanu Ibiam Federal Polytechnic Unwana, Afikpo Ebonyi State Nigeria.
Department of Building Technology, Akanu Ibiam Federal Polytechnic Unwana, Afikpo Ebonyi State Nigeria.

ABSTRACT: An updraft gas kiln was fabricated from mild steel sheets and refractory bricks made from Nsu clay and Otammiri river sand. The metal encasement of the kiln measured 70 cm x 62cm x 80cm. Two burner ports were provided on one side of the kiln, measuring 6cm eac in diameter. The chimney hood measured 34cm x 24cm x 96cm The refractory bricks were composed of 70% Nsu clay, 5% Otammiri river sand, 20% fireclay grog and 5% commercial grade alumina. 40% by weight of sieved sawdust was added to the batch for the porous refractory bricks. The effective percentage alumina content of the body composition of the bricks was 29.54% and the effective percentage silica content was 57.21%. The theoretical maximum service temperature for refractory bricks of such composition is 1470^{O}C. The new kiln was test fired successfully to a temperature of 1260^{O}C which was reached in seven hours. Significant amounts of impurity fluxing oxides in the raw materials makes the recommended maximum service temperature of 1250^{O}C, quite lower than the theoretical value. It is recommended to add up to 5 – 10 % of commercial grade alumina and up to 25% Calcined fireclay to the body composition of bricks produced from these local raw materials, to improve high temperature stability.

KEYWORDS: Refractory, kiln, fireclay, silica, alumina, grog.

I. INTRODUCTION

A kiln is any of several kinds of insulated chamber, heated electrically or by means of a fuel, used to fire ceramic products, roast ores, or in the production of cement. Kilns are essential, not only in the production of ceramic wares, but also in the teaching and learning of ceramic technology.
Kilns may be generally classified into two broad types, based on their heat source-electric kilns and fuel fired kilns, (Idowu et al 2015). Electric kilns are heated by radiant heat produced by the conversion of electrical energy to heat energy in heating elements, (Olsen, 2001). Electric kilns nowadays, often use elements made of special high temperature alloy of iron-aluminium-chrome. This alloy can withstand very high temperature of up to about 1015℃, (Lewicki, 2014).

Fuel fired kilns are heated by the combustion of carbonaceous materials which may be firewood, coal, charcoal, sawdust, various oils, and gas, (Asante-Kyei et al 2019). Various fuel types have their own merits and demerits, however most modern fuel fired kilns utilize gas as fuel due to its availability, clean burning and ease of control.

Unlike oil burners, gas burners are simple, inexpensive and fool proof, (Oteng 2011). Norton (1956) indicates that gas kilns can achieve very high temperatures. According to him, well-designed gas kilns give uniform temperature and may be used up to 1450 ºC (cone 16). This permits the attainment of uniform temperature with greater ease.

In comparison, firing with electricity usually costs twice as much as firing with gas (Oteng, 2011). In addition, varieties of rich visual textures are achievable with gas kilns due to the possibility of neutral, oxidation or reduction firing, which cannot be achieved with electric kilns, (Oduagwu et al 2015).

Gas kilns may further be classified according to the method of flow draft. Updraft kilns are those in which the flame is introduced into the bottom of the kiln, at or below floor level, and exhausted out the top. Updraft kilns consist of three basic components: the firebox, the damper, and the stack area.
The firebox is where the flame enters. The damper is at the top of the kiln and controls the exhaust (and, by association, the kiln's atmosphere). The stack area is where the wares are set and it's between the firebox and damper. Although an updraft kiln tends to be less fuel efficient than a downdraft kiln, most commercially built fuel-burning kilns are updrafts. This is mainly due to their simplicity to build, pack, and ship. (Peterson 2019).

Downdraft kilns are designed to force the flame and heated air to circulate through the kiln. Flame is introduced at the bottom of the kiln and naturally flows upward. The construction forces the flame back downward, to exhaust at the bottom of the kiln. Downdraft kilns consist of four main components: the firebox, the stack area, the damper, and the chimney. The addition of the chimney helps create draw or air flow, (Peterson2019).

A damper is usually a piece of refractory material, often a kiln shelf that is placed in the path of the flue gases as they travel up through the chimney stack of the kiln. By moving it in and out, the pressure inside the kiln is controlled. Increased pressure decreases airflow, and decreasing pressure increases airflow, (Frenzel 2010).

There are also other less common flow draft configurations, including cross draft kilns, which rely on movement of heat from the inlet flues on one side of the kiln chamber to the exit flues along the opposite side. The critical factors and principles involved in the design and fabrication of gas kilns are described in detail by Olsen (2010).

Refractory fireclay is the most commonly used material for lining ceramic production kilns, (Iyasara et al 2014). The SiO_2-Al_2O_3 system shown in fig.1 shows the range of temperature within which refractory fireclay bricks are stable, (Mark et al 2011).

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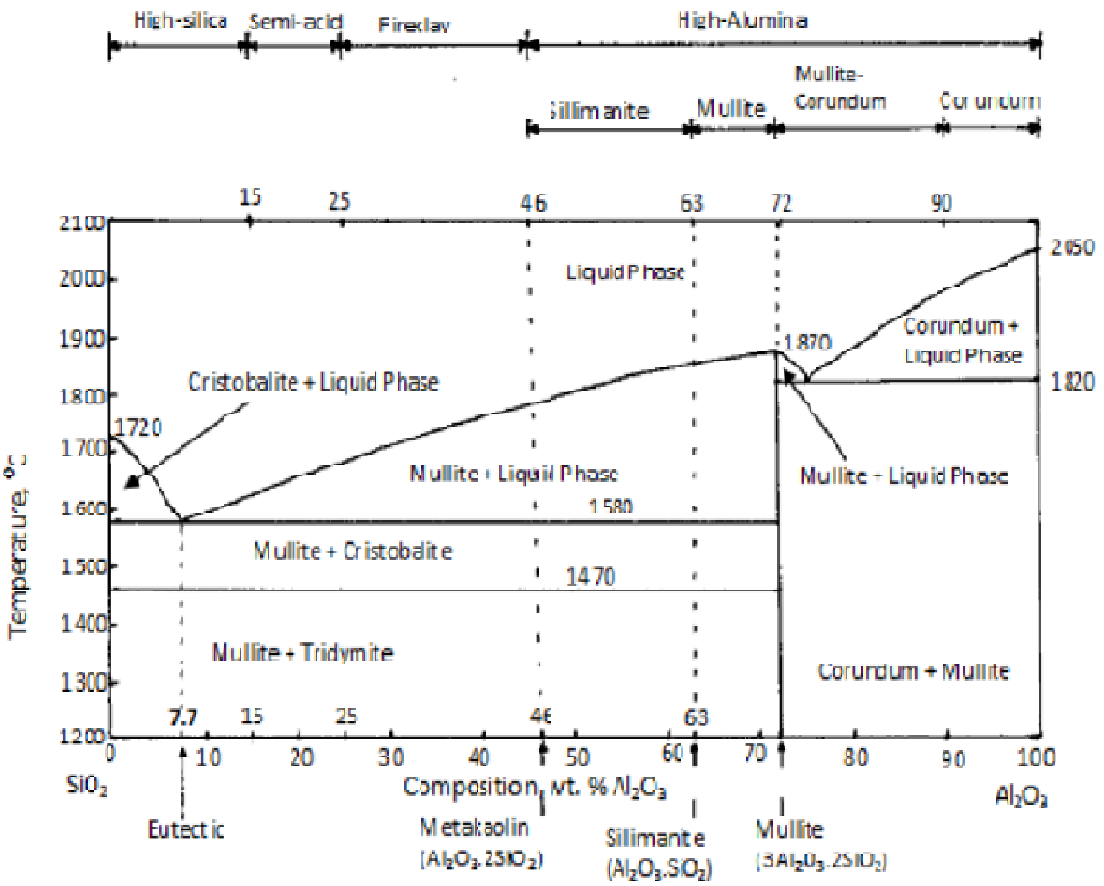

Figure I: SiO_2 – Al_2O_3 System showing subgroups of aluminosilicate refractories {Adapted from Krivandin and Markov (1980); and Callister (2007)}

II. DESCRIPTION OF STUDY AREA

The refractory bricks used to line the kiln were produced and installed at the ceramic workshop of the department of Ceramic and Glass Technology, Akanu Ibiam Federal Polytechnic Unwana. The metal shell of the kiln was fabricated in a welding workshop. The gas burners were also machined in the welding workshop.

III. MATERIALS AND METHODOLOGY

The materials used for the production of the refractory bricks are Nsu clay, a kaolinitic fireclay, Otammiri river sand, commercial grade alumina and fireclay grog.

The metal shell of the kiln was welded from 2mm thick mild steel sheets with 4 x4 cm angle iron round the edges to enhance load distribution. The cuboid structure measured 70 cm x 62cm x 80cm. Two circular openings measuring 6cm in diameter were provided on one side of the cuboid for the burner inlet. On the opposite side, a rectangular flue opening measuring 20cm x 20cm was provided leading into the chimney tower.

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The chimney tower measures 34cm x 24cm in cross sectional area and have a height of 96cm. An updraft design was chosen for its superior heat circulation potentials. Commercial grade calcium aluminate refractory cement and refractory fireclay grog were used to prepare the mortar for the installation of the bricks.

The batch composition of the clay body for the refractory bricks is as shown in table 1 below.

Table 1. Batch composition of clay body for refractory bricks.

Raw material	% composition
Nsu clay	70
Otammiri river sand	5
Fireclay grog	20
Commercial grade alumina	5

40 % by weight of sieved saw dust was added to the batch used to produce the insulating (porous) refractory bricks. The raw materials were all crushed and milled separately and sieved into three particle sizes, coarse (mesh 10 – 2000microns), medium (mesh 25- 710 microns) and fine (mesh 70- 212 microns) respectively.

Optimal packing density was enhanced by combining the portions in the following proportion; 60 % coarse, 10% medium and 30 % fine as reported by Samad et al (2021).
A manual hydraulic compaction press was used to compact the bricks. Two standard brick sizes were produced, measuring 24 x 13 x 6 cm and 5.5cm x 5cm x11.5cm. The bricks were allowed to dry in open air for 21 days before being fired in a gas kiln at 1200 ^{O}C.

IV. RESULTS AND DISCUSSION

Table 2 below, shows the chemical analysis of Nsu clay as reported by Iyasara et al (2014), while table 3 shows the chemical analysis of Otammiri river sand used in the production of the refractory bricks as reported by Osonwa etal (2022).

It can be seen from the chemical analysis results of the clay that the alumina content is well within the range that will enable the clay to be classified as a refractory fireclay.

Table 2. Chemical analysis of Nsu Clay. (Adapted from Iyasara et al 2014).

Oxide	Wt. %
SiO_2	59.2
Al_2O_3	26.3
MgO	0.62
Fe_2O_3	2.01
Na_2O_3	-
K_2O	0.2
LOI	12.71

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Table 3. Chemical analysis of Otammiri river sand. (Adapted from Osonwa et al 2022).

Oxides	% Composition
SiO_2	86.65
Al_2O_3	4.42
Y_2O_3	2.51
Fe_2O_3	1.41
SO_2	1.19
CaO	0.98
Cl	0.88
K_2O	0.75
TiO_2	0.68
MgO	0.25
P_2O_5	0.16
Na_2O	0.12

On a 100kg batch weight basis,

Weight of Nsu clay = 70kg

Alumina contribution from Nsu clay at 26.3% = $\frac{26.3}{100}\ x\ 70 = 18.41\ kg$

Silica contribution from Nsu clay at 59.2% = $\frac{59.2}{100}\ x\ 70 = 41.44\ kg$

Weight of Otammiri river sand = 5kg

Alumina contributon from Otammiri river sand at 4.42% = $\frac{4.42}{100}\ x\ 5 = 0.221\ kg$

Silica contribution from Otammiri river sand at 86.65% = $\frac{86.65}{100}\ x\ 5 = 4.33\ kg$

Total alumina content of bricks = 18.41 + 0.22 + 5 = 23.63 kg

Total silica content of bricks = 41.44 + 4.33 = 45.77 kg

Since the fireclay grog has been calcined at 1000Oc, it will be unreactive in the brick at temperatures below 1000Oc.

Therefore, effective percentage alumina will be $\frac{23.63}{80}$ x 100 = 29.54%

Effective silica percentage will be $\frac{45.77}{80}\ x\ 100 = 57.21\ \%$

From the SiO_2-Al_2O_3 phase diagram, we can see that refractory bricks made of this composition would be thermally stable up to about 1470^{O}C, where the predominant high temperature phases would be mullite and tridymite. Beyond this temperature, crystobalite phase is formed with attendant volume changes which may cause the bricks to warp, distort and fail, even though liquid phases are not yet present.

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The kiln successfully reached a temperature of 1260^{O}C in approximately seven hours, during the test firing. The significand amounts of fluxing oxides such as CaO, Fe_2O_3, K_2O, etc. in the composition of Nsu clay and Otammiri river sand, could however limit the attainment of much higher temperatures practically, as liquid phases could form below theoretically expected temperatures. Thus the recommended maximum service temperature is 1250^{O}C.

V. CONCLUSIONS AND RECOMMENDATIONS

From the results discussed above, it can be concluded that refractory bricks produced from Nsu clay and Otammiri river sand can be successfully utilized in the lining of ceramic kilns. It can also be concluded that such locally formulated refractory bricks can be used up to a maximum service temperature of 1400^{O}C, although presence of fluxing oxides in the composition of the raw materials could make the practically safe maximum temperatures quite lower than the theoretical value.

It is recommended to add up to 5 – 10 % of commercial grade alumina and up to 25 % calcined fireclay to the body formulation for the bricks, to improve high temperature stability.

VI. APPRECIATION

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