DESIGN AND CONSTRUCTION OF GAS TEST KILN FOR HIGH TEMPERATURE APPLICATIONS USING FIBREGLASS

ADINDU C. IYASARA[1]*, VICTOR C. NWACHUKWU[1], LILIAN C. IZUEGBU[2]
[1]Department of Ceramic and Glass Technology
[2]Department of Metallurgical Engineering Technology,
[1,2]Akanu Ibiam Federal Polytechnic, Unwana, Nigeria

**Corresponding author: Email: acnnayerugo@gmail.com; Phone: +2348037390071*

ABSTRACT

A gas test kiln was designed and constructed for analytical purposes and high temperature (1000 to 1200 ^{0}C) applications. The kiln was developed using materials and technologies sourced locally and it consists mainly of heating chamber made of fibre glass and refractory cement at the base. The fibre glass replaces the insulating bricks used in a conventional kiln for the side lining while the refractory cement formed the hearth. By using fibreglass and refractory cement as thermal insulating materials in this work, a light weight test kiln with reduced thermal shock effect and cost effective when compared to conventional kilns was constructed. The production cost is approximately fifty-nine thousand, seven-hundred-naira, ₦59,700 ($143.17) while an imported test kiln of similar capacity costs between eighty –three thousand, three hundred and ninety-nine-naira, ₦83,399 ($200) and one hundred and four thousand, two hundred and fifty-nine-naira, ₦104,249 ($250) excluding importation and transportation charges. Therefore, the fabricated test kiln is as good as the foreign based (imported) ones. Because the constructed test kiln is enhanced and cost effective too, its mass production will be a welcomed development and a boost to our economy.

Keywords: Design, test kiln, fibreglass, refractory cement, thermal shock.

INTRODUCTION

Ceramics are products of high temperature processes and these processing reactions usually take place within a thermally insulated enclosure such as oven, kiln, etc. A kiln is an enclosure or a thermal plant made of refractory materials with controlled heating system to fire finished or semi-finished ceramic products (Hansen, 2017). Kilns can be classified according to heat source as fuel (gas) fired kiln, solar kiln, and electric kiln (Idowu & Tunmilayo, 2013). However, there are different types of kilns such as continuous kilns and periodic kilns used for ceramic science and technology (Boateng, 2016). During usage, continuous kilns are unceasingly firing and are never cooled except during maintenance. The items to be fired are placed into cars or conveyor belts and then slowly moved through the kiln. Continuous kilns are mainly used for industrial manufacturing. Examples of continuous kilns include tunnel kiln, pusher slab kiln, conveyor-type kiln, rotary kiln etc. Periodic kilns are applied for intermittent firing and are used most often by potters. The items are loaded into the kiln; the temperature is set, and then cooled after firing, unloaded and reloaded for subsequent firing. Examples of periodic kilns are updraft kiln, downdraft kiln, spring arc kilns, cat nary arch kilns, bottle kilns etc. When the kiln has relatively small dimension and utilized for preheating or heat treatment of specimens in small quantities, it is termed a test kiln (Hansen, 2017).

Conventional kiln is made of refractory bricks as the lining materials. Due to the lining of the kiln with refractory bricks and their corresponding heavy weight, its transport may seem difficult. Also, with the use of refractory bricks for kiln lining, thermal shock due to opening of the kiln is likely to occur emanating from the properties of the bricks (Rhodes, 1968). In addition, most conventional kilns available in our tertiary institutions, research centres and companies are imported. To eliminate these inadequacies, this project aims at fabricating a local, cost effective and light weight test kiln for easy carriage as well as reducing thermal shock effect using fibreglass. A glassfibre is a fine fibrous material produced by extruding glass at high temperature and rapidly drawn into a fiber with 3-20 μm in diameter (Richerson & Lee, 2018). It is used for lining kilns because of its excellent properties such as non-combustible, non-decay, high temperature resistance, sound adsorption, heat insulation, good chemical stability and brittleness (Guatam et al., 2019).

Fibreglass fabricated kiln has many advantages over refractory bricks kiln (Caihua, 2019). These merits include low thermal conductivity (0.04 W/m. K) (Huge, 1992), low bulk density (180 kg/m^3), good flexibility and softness; and excellent thermal shock resistance. It has been proven that the ordinary ceramic fibreglass can be used as the lining in kiln below 1000 ^{0}C thereby reducing the energy cost by 15-30 %, while the middle grade ceramic fibreglass when used as a kiln lining at about 1300 ^{0}C can reduce the cost by 10 -30 % (Richard, 2018).

MATERIALS AND METHODS

Materials

The materials used to fabricate the gas test kiln include: fibreglass (1050 x 600 x 70 mm), 450 mm x 450 mm x 50 mm flat mild steel, 1.5mm thickness angle bar, refractory cement (15 Kg), hinges, fillers and paint.

METHODOLOGY

The construction of the test kiln using fibreglass is categorized into two major sections namely fabrication of the metal casing and cement work /coupling of the fibreglass.

Fabrication of the metal casing

The framework structure of the test kiln was performed in the fabrication workshop of the Department of Metallurgical Engineering Technology, Akanu Ibiam Federal Polytechnic, Unwana, (AIFPU), Nigeria. The flat metal sheets and angle bars were measured to required dimensions with the measuring tape and cut to sizes using metal cutter and hacksaw. The cut bars were welded together using arc welding machine, forming a three-dimensional cube-like frame. The door side of the kiln was selected and fabricated to fit-in for opening and closing of the door using angle bar and hinges. The dimension of the kiln's door fabricated from mild steel sheet was 450 x 450 x 50 mm.

A 40.50 mm diameter hole was drilled near the centre of the kiln's floor to serve as the chimney. A chimney is a vertical channel or pipe which conducts smoke and combustion of gases up from the kiln. Other parts of the framework such as the handles and balance base were joined Then, debris and rough surfaces of the metal casing were smoothened using emery paper of different grits while the gaps at the edges and joints were closed using fillers.

Cementing and Coupling of the Fibreglass

The cement work and assembling were carried out in the workshop of the department of Ceramic and Glass Technology, AIFPU. The inner part of the kiln comprises of the hearth (floor or base) and the walls. The hearth was made using the refractory cement while the walls were made of fiberglass. Before the hearth was made, the section to be cast was marked out using a marker and plywood was used for the formwork onto which the refractory mortar sets.

The refractory cement was mixed with water to form a mortar and transferred into the formwork of the metal casing using hand trowel. With the aid of the hand trowel, the heaped mortar was leveled and allowed to set for about 2 hours. The fibreglass was then measured according to the sides of the casing and placed into the casing with the burner's port and chimney holes created on the sides of the fibreglass. The top of the test kiln was also covered with fibreglass and all edges were lagged with refractory cement to avoid heat loss during heat treatment. On completion of the interior works, the top (cover) of the kiln was welded. The body (metal casing) was then painted to add aesthetic value to the fabricated test kiln.

Design, calculations and costing

Design

The design of the test kiln was accomplished using 18 gauges flat metal sheets (mild steel), 1.5mm thickness angle bars (8 pieces of length 450 mm and 4 pieces of length 650 mm for the sides and stand, respectively of the casing), 15 Kg of refractory cement, and fibreglass (1050 x 600 x 70 mm dimension). The schematic of the angle bars is shown in Figure 1. Welding the angle bars together gave a three-dimensional frame structure (Figure 2). The design of the constructed test kiln is presented in Figure 3.

The optimal performance of the welded frame structure for the test kiln is guaranteed by eliminating or minimizing the residual stress introduced therein during the welding operation via post weld treatment. In this work, hammer peening (a type of shot peening) was employed. Hammer peening involves striking the metal surface (including the welded joints) by a round or spherical shot containing metallic, glass or ceramic particles with enough force to generate compressive stress (Askeland et al., 2010). Hammer peening is also expected to reduce stress corrosion or strength fatigue, etc. (Young, 2022)

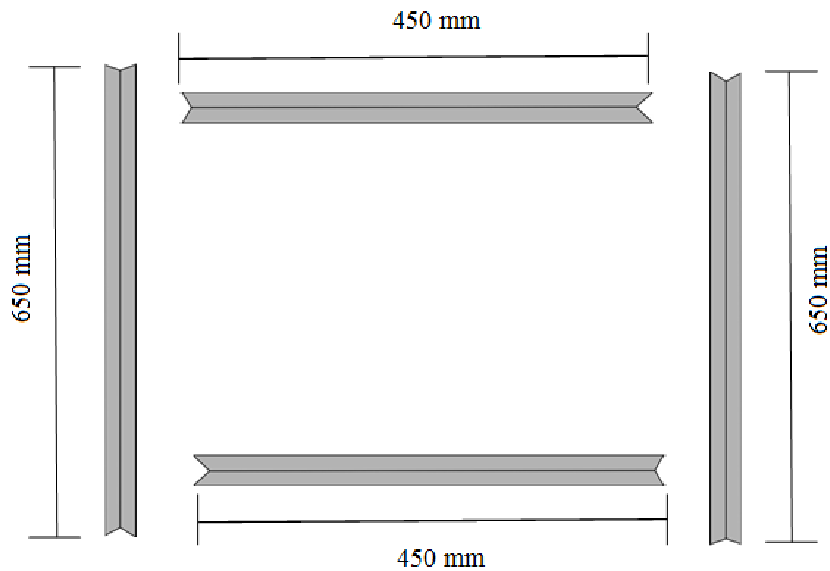

Figure 1. Schematic of the angle bars for sides and stands of the test kiln

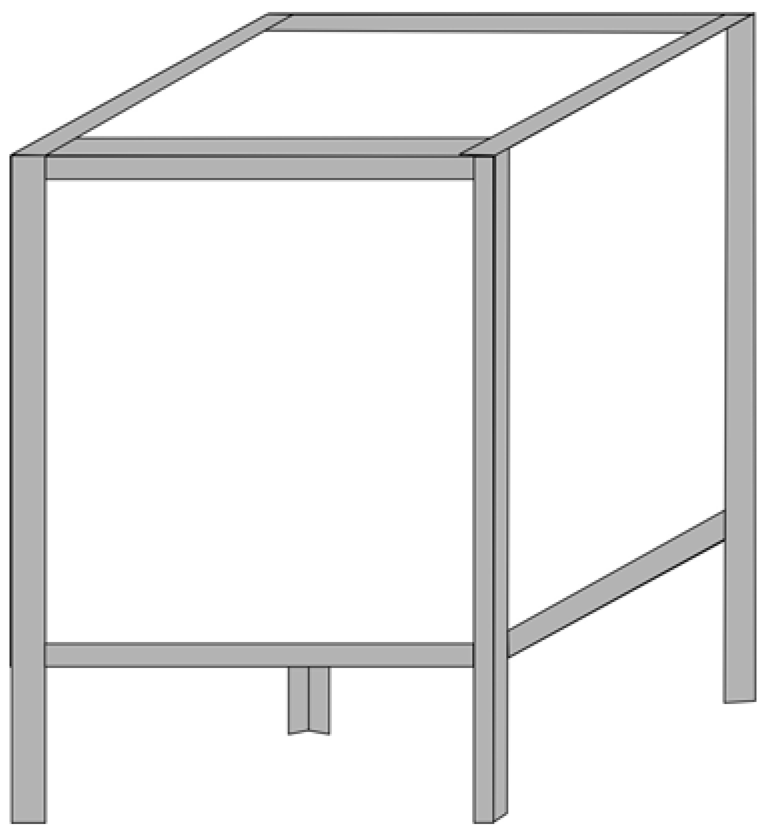

Figure 2. The 3-dimensional view of the welded angle bars of the kiln

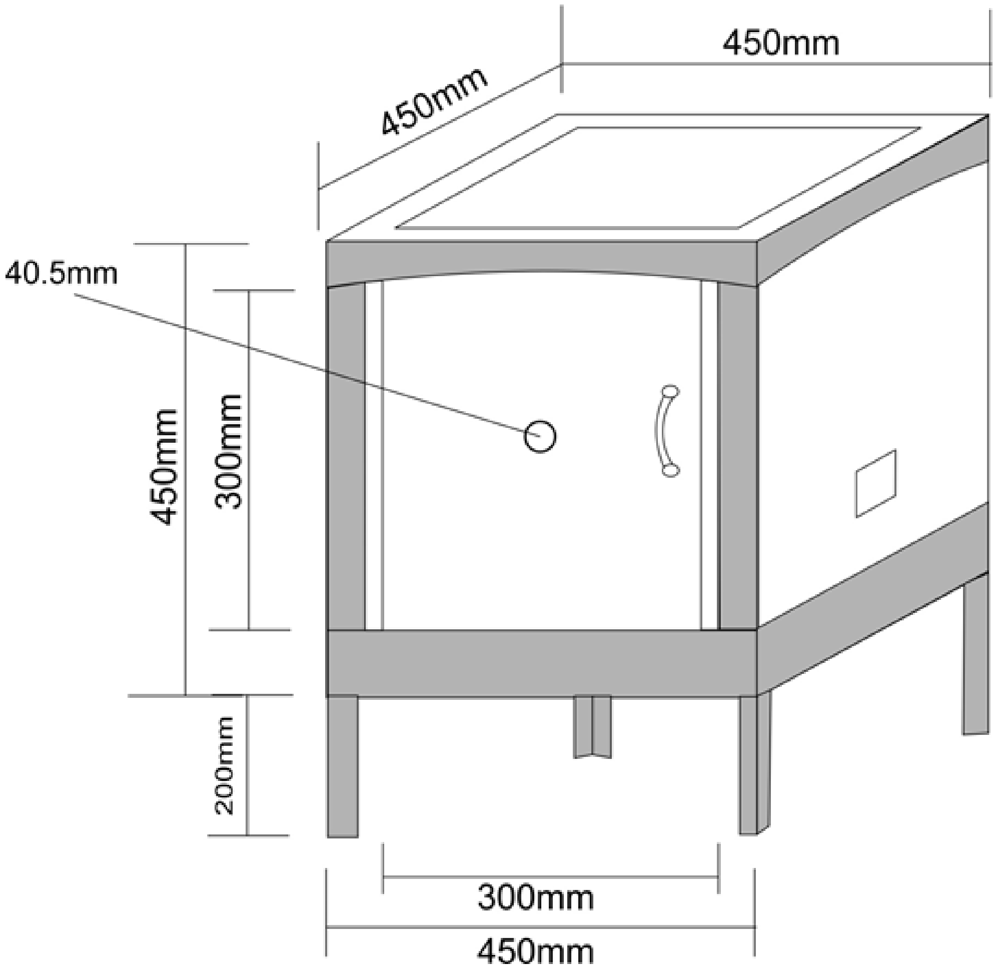

Figure 3. Design work of the constructed test kiln with dimensions

Calculations

i. Kiln capacity (volume): The interior volume of a front-loading kiln, V_k is calculated using the following equation (Ward, 2014):

$$V_k = W * H * D \tag{1}$$

where, W = Width of the kiln = 300 mm (0.3 m), H = Height of the kiln = 300 mm (0.3 m) and D = Depth of the kiln = 300 mm = 0.3 m.

$$\therefore V_k = 0.3 * 0.3 * 0.3 = 0.027\ m^3 = 0.089\ ft^3 \tag{2}$$

ii. Cross-Sectional Area of the Kiln's Heating Chamber

The interior cross-sectional surface area of the kiln was computed using equation 3:

$$Surface\ area = Length * Width \quad (3)$$

Therefore, Surface Area $= 0.3 * 0.3 = 0.09\ m^2$

Cost Evaluation

The construction of the test kiln involved various materials and their costs are presented in Table 1. The cost of purchasing a gas fired test kiln made with refractory bricks ranges from $200 to $400 (₦83,399.66 to ₦104,249.57) excluding importation and transportation charges. However, the cost evaluation (Table 1) depicts that the locally fabricated test kiln using fibreglass is cost effective when compared to the imported test kiln using refractory bricks. The photograph of the constructed test kiln is shown in Figure 4.

Table 1. Cost evaluation of the constructed test kiln

S/N	MATERIALS	AMOUNT	
		₦	$
	Fibreglass	25,000	59.95
2	Metal sheet (mild steel and angle bars)	9,700	23.26
3	Refractory cement	15,000	35.97
4	Miscellaneous and transportation	4,000	9.59
5	Welding and coupling	6,000	14.39
	TOTAL	**59,700**	**143.16**

1US Dollar ($) equals 417 Nigerian Naira (₦) (Central Bank of Nigeria, 2021)

Figure 4. Photograph of the constructed test kiln.

CONCLUSION

Design and construction of a gas test kiln using fibreglass and refractory cement was carried out. The construction design is simple and provided an avenue for easy maintenance, repair and modification. The test kiln is expected to operate at a high temperature up to 1200 ^{0}C. With the construction of this test kiln with fibreglass, the identified problems associated with conventional kilns, e.g., thermal shock, heavy weight and difficulty in transportation etc. have been eliminated. Therefore, the fabricated test kiln is as good as the foreign based (imported) ones. Because the constructed test kiln is enhanced and cost effective, its mass production will be a welcomed development and a boost to our economy

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