Design and Construction of a Coal-Fire Kiln for Recycling of Waste, Using Refractory Bricks.

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Abstract

This study centres on the design and construction of a coal-fire kiln for recycling of waste, using refractory bricks. The materials with which the kiln is built for effective performance matter and it is of utmost importance. Hence, a heat resisting and sufficiently refractory material that can withstand extreme temperature which the kiln is exposed to, immediately comes to mind. Recycling is a key component of modern waste reduction and is the third component of the "Reduce, Reuse, and Recycle" waste hierarchy. It promotes environmental sustainability by removing raw material input and redirecting waste output in the economic system. An essential aspect of kiln design and construction is the ability to be able to identify the right types of bricks that will yield the desired result. The study used refractory brick from clay and kaolin to construct a burning furnace to control waste in the environment. The study therefore recommends that industries that turn our waste should make the effort of acquiring firing equipment that has the capacity of recycling the waste they turn out into wealth and that the government should be fully involved in waste recycling as it will also boast the economy of the nation.

Keywords: refractory, recycle, bricks, kaolin.

Kiln is an essential component of the manufacture of all ceramics. Ceramics require high temperatures, so that chemical and physical reactions will occur to permanently alter the unfired body (Fajuyigbe, 2006). In the case of pottery, clay materials are shaped, dried and then fired in a kiln. The final characteristics are determined by the composition and preparation of the clay body and the temperature at which it is fired. Clay consists of fine-grained particles that are relatively weak and porous. Clay is combined with other minerals to create a workable clay body. Part of the firing process includes sintering. Ebeigbe (2006) explained that, the firing process heats the clay until its particles partially melt and fuse together, creating a strong, single mass, composed of a glassy phase interspersed with pores and crystalline materials. Through firing, the pores in the clay are reduced in size, causing the material to shrink slightly.

Recycling is the process of converting waste materials into new materials and objects. This concept often includes the recovery of energy from waste materials. The recyclability of a material depends on its ability to reacquire the properties it had in its original state. It is an alternative to "conventional" waste disposal that can save material and help lower greenhouse gas emissions. It can also prevent the waste of potentially useful materials and reduce the consumption of fresh raw materials, reducing energy use, air pollution (from incineration) and water pollution (from landfilling).

Recyclable materials include many kinds of glass, paper, cardboard, metal, plastic, tires, textiles, batteries, and electronics. The composting and other reuse of biodegradable waste—such as food and garden waste—is also a form of recycling. Materials for recycling are either delivered to a household recycling center or picked up from curbside bins, then sorted, cleaned, and reprocessed into new materials for manufacturing new products.

In ideal implementations, recycling a material produces a fresh supply of the same material—for example, used office paper would be converted into new office paper, and used polystyrene foam into new polystyrene. Some types of materials, such as metal cans, can be remanufactured repeatedly without losing their purity. With other materials, this is often difficult or too expensive (compared with producing the same product from raw materials or other sources), so "recycling" of many products and materials involves their *reuse* in producing different materials (for example, paperboard). Another form of recycling is the salvage of constituent materials from complex products, due to either their intrinsic value (such as lead from car batteries and gold from printed circuit boards), or their hazardous nature (e.g. removal and reuse of mercury from thermometers and thermostats). In other for these waste materials not to affect the lives people around the area, there is the need to recycle the wastes to become useful in the environment. In doing this, a lot of equipments and machines are needed and such is the kiln.

A melting furnace is a type of equipment used to heat materials, usually for an industrial application. They generally differ in terms of the types of materials they can heat, the temperatures they can generate, and how they function. Some of the most common types of furnace are electric arc furnace and crucible furnace. Furnaces have been used by people for a very long time. The earliest furnace is believed to have originated with the Hindus valley civilization of Indians between 2500 and 1800BC (Maurya, 2002). The melting furnace is an industrial version of this concept and is typically used for the production of specific materials through their heat sources (Maurya, 2002).

Waste management should be the concern of every Nigerian. The waste turn out in our environments causes various health hazards. Waste gets us sick, they injure us, they keep the environment dirty and untidy. To this effect, there should be wake up call to everyone to stand up in remedying these situations. Recently, there has been a campaign of waste to wealth. This call should be answered as to reduce the hazardous effects pose to the environment from waste disposed.

The objective of this study is to answer the call of waste to wealth by designing a kiln with refractory brick for recycling of waste in the environment.

Bricks and brick production

"The term brick simply means a small unit of building material often made from fired or baked clay. Brick is a fired clay block used for building. Bricks are generally used for the construction of kiln furnaces, crucibles (a heat-resistant container for melting ores), etc. it is a key component used during kiln construction because of their capability of retaining heat, resisting corrosion as well as refractoriness (Ali, 2013)."

Some of the factors to be considered during the process of brick selection are refractoriness and insulation. The discovery of insulating bricks is one of the greatest improvement in brick making. The development of insulating bricks (light weight bricks) has expanded the range of temperatures possible in kiln design and firing (Ali, 2013). 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."

Plate 1. Bricks
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In ceramics, bricks are classified into two main categories: refractory bricks and insulating refractory bricks. Ali (2013) states that the 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 of the surface of the earthis continuous,it goes on everywhere.It is an extremely common and abundant material in nature". According to Ali (2013), virtually all clays are insulated and resist heat to certain degrees. Ali notes that primary clay or kaolin ($AI_2O_3.SiO_22H_2O$) 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 withstand the action of corrosive solids, liquids, or gases at high temperatures. A clay body may consists 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 a good type of clay for the manufacturing 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 clay and these are refractory clay with melting point that ranges from 1300^oC to 1750^0C. Some fire clay are as refractory as China clay and are able to withstand temperature of about 1750^oC without deformation and probably melt around 1800^oC (Ali, 2013).

Cardew (2002) states that the bricks must not only be able to withstand the temperature, but must also be reasonably immune from spalling (the tendency to break away in flakes of the face, at the edges or at the corners). Spalling is a special case of poor thermal shock resistance and is usually caused by 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."

Refractory materials

"The most useful and most refractory material that can be used for kiln construction in Nigeria is pure kaolin or kaolinite ($Al_2O_3.2SiO_2.2H_2O$), and has a melting temperature (point) of 1785^0C (Ogumor, 2007). However, most clay deposits of this nature inNigeria contain impurities such as iron and some other traces of alkalis and other oxides in addition to alumina and silica, which to a high degree reduces the melting point of the clay below 1785^{0}C (Ogumor, 2007). Some of the refractory materials that could be used are:"

Fired bricks (from clay)

"Brick is the most common material used in kiln construction. It is utilized in the basic electric kiln, the small gas-fired studio kiln, large wood-fired kilns, and mammoth industrial tunnel kilns (Jacobson, 2010).Ogumor (2007) opined that bricks made from fired clay are usually made with a lot of grog and fired at about 1300^{0}C or higher. Fired clays can be described as any clay that will withstand the higher temperature, normally above 1000^{0}C (Ogumor, 2007).Fired clays are mostly found in connection with seams of coal and in Nigeria, one can obtain the clay mostly from Benin – Edo State (Ogumor, 2007). Fired clay vary in plasticity and possess properties such asbetter density, strength, well graded particle size, refractoriness, volume, resistance to spalling and cracking, resistance to acids and slagsand,exactness in size (Ogumor, 2007).Ogumor (2007), further outlined some advantages of fired bricks as follows:"

i. They are refractory and will go beyond the highest temperature used ordinarily for ceramic works.
ii. They are hard, dense and resistance to wear out and abrasion;
iii. They can resist spalling and cracking;
iv. They do not crumble or disintegrate easily;
v. They are relatively cheap and can be obtained locally and they come in a number of shapes to facilitate kiln construction.

"Similarly, Ogumor (2007) revealed that fire bricks are made in four grades or qualities depending on the degree of temperature they can withstand. These include:

i. Super duty;
ii. High duty – suitable for kiln building;
iii. Medium heat duty;
iv. Low duty – made for use in boilers, fire places and other place of mild heat."

"The basic standard shape of fired bricks is 9 inches straight (mostly, $9x6^{3}/4x2^{1}/_{2}$ inches) (Ogumor, 2007). This size measurement varies depending on the shape of the brick. Some examples of these standard measurement as described by Ogumor (2007) are:"

i. Soap (brick) $9x2^{1}/_{2}x2^{1}/_{2}$ inches
ii. Wedge (No1) $9x4^{1}/_{2}x2^{1}/_{2}x1^{7}/_{8}$ inches
iii. Arch brick (No1) $9x4^{1}/_{2}x2^{1}/_{8}x2^{1}/_{2}$ inches
iv. Edge skew $9x4^{1}/_{2}x2^{1}/_{2}x1^{1}/_{2}$ inches

Insulating Firebricks

"According to Jacobson (2010), insulating firebrick does exactly what the name implies. It acts as an insulator, allowing only a small amount of heat to penetrate the surface of the brick and reflecting the heat back into the interior of the kiln. The brick is made of refractory materials and formed by a process which allows numerous small pockets of air to be incorporated into the brick—allowing the insulating quality (with less heat storage) but maintaining the structure for strength (Jacobson, 2010). Similarly, Jacobson (2010) reported that common manufactured Insulating firebricks have many temperature ranges of about 2300°F (1260°C); 2600°F (1427°C); 2800°F (1538°C); and 3000°F (1649°C) respectively."

"Insulating fire bricks are usually referred to as 'soft' bricks, which are mostly designed especially for greater heat retention (Ogunsina, 1992). According to Ogunsina (1992),insulating fire bricks are of two kinds namely:"

i. "Diatomaceous earth bricks- made from the natural deposits of the diatom, a small sea animal whose myriad shells have formed thick marine deposits. Such materials are soft, light, porous and contain a great proportion of silicon dioxide.

ii. Insulating bricks can also be made from refractory fire clay and kaolin. This is the type we can make locally here in Nigeria."

"Ogunsina (1992)went further to explain that there are two ways of making clay insulating bricks. This is achieved either when the clay is mixed in to a heavy slip and air bubbles are induced into it by chemical means and the clay is dried, fired and cut into brick shapes. The second is the one most often made by local professional potters in Nigeria. This involves mixing the clay with combustibles such as sawdust, shells, etc. In this method, the bricks aremolded, dried and later fired. The combustibles will burn off leaving entrapped air pockets which make a light porous brick with high insulating properties and with excellent resistance to heat especially if made from the proper kaolin clay (Ogunsina, 1992). Insulating bricks help to increase the heat retention properties of kilns. They can either be used in constructing the entire kiln structure or they may be used as back-up layer behind regular hard fire bricks."

"The secret behind the higher heat retention (insulating) property of insulating bricks are because of the presence of entrapped voids in the structure left as a result of the combustible material that has been mixed with the material and which is later burnt off leaving the void (Ogunsina, 1992). The loose association of the particles hinder the flow of heat by conduction. Hence, an insulating brick which is heated up to red heat at one end can easily be picked up in the hand at the other end of it. One other advantage that insulating bricks have over the hard fire brick is that, a kiln made up entirely of the latter will require more fuel just to heat up the kiln itself before the wares, whereas insulating brick kiln require less fuel. Though it must be taken into consideration that a kiln built entirely with insulating (soft) bricks will have a shorter life span comparative to that of hard bricks. The best method is to use hard fire brick for the outer lining of the kiln and the insulating bricks for the inner lining (Norton, 1994)."

Building the coal-fire Kiln

"James Watkins, with some help from Randy Brodnax, demonstrates how to put together a coal-fire kiln. Their construction features some innovative design modifications that increase its efficiency, such as a baffle system and a modified burner orifice." In this construction, a popular alternative design joins the lid to the cylinder, often referred to as "Topha" kiln, but to open it the entire affair must be raised off its brick pad with a pulley-lifted device. James finds the former design to be equally effective and easier to build. "This according to these authors is nice and easier to build. They further explained that, it is necessary to have an assistant who helps to remove the lid for the constructor, so that the work wound not cool down too much before one starts the reduction process."

"They explained that one of the key requirements in the construction process is adequate space, clear of combustible materials, above and around the kiln. Similarly, to protect the kiln from the weather, one should consider locating it under an open-sided shelter, with at least 8 feet (2.4m) of clearance overhead so that smokes can escape."

"Removing the material from the kiln and placing it in the reducing chamber should be a smooth and an uninterrupted action. It is advisable to clear any objects that might intrude into the kiln to the reduction chamber before you start firing the kiln. Ideally, the reduction chamber should be close enough to the kiln so that it will be possible to remove the materials and place it in the chamber in one easy step. It is also necessary to position the propane gas tank at least 8 feet (2.4 m) away from the kiln, but keep it inside the burner port. Get the proper instruction from a technician or from the tank's manufacturer on how to make the connections and be sure to check for gas leak."

"The fine particles in fiber, the blanket insulating materials are a health and environmental hazards, particularly after the first firing. It is of utmost importance that you wear a respiratory gadget fitted with an appropriate canister and filters while handling the blanket material. Do not expose your skin to the fibers either. Consider using an improved blanket material, such as one made with a new soluble, high-temperature insulating fibers. One can find sources for it through a ceramic supply house or on the internet."

Materials and tools to build a coal-fire Kiln

These materials were chosen for their strength and ability to withstand heat, or sometimes for safety reasons. These are: 2 half-circle kiln shelves; 16-gauge expended metal with ½ - inch(1.3cm) openings, 4x8 feet (1.2x2.4 m) sheet; Lumber crayon; Heavy-duty wire cutters; 1-inch (2.5 cm) insulation fiber blanket; 6 pcf (96 kg/m^3); Permanent marker; Heavy-duty scissors; 18gauge nichrome refractory wire; 2 pairs of pliers; Twenty-four 2-part fiber anchor pins, 2 inches(5 cm) long, rated for a minimum of $2{,}100^0$F ($1{,}149^0$c); or 24 clay buttons; Utility knife; 2 metal cabinet handle, with bolts, washers, and nuts to attach them; 18 hard firebricks; 22 soft firebricks, rated to$2{,}300^0$F ($1{,}260^0$C);Venture burner capable of Producing 165,000 BTU with Propane or 60,000 BTU with natural gas, with appropriate hose fittings, high-pressure regulator, and needle valve; Solve setup: solder, solder past, square of heavy-duty aluminum foil, and soldering torch drill with 1/16-inch (1.6 mm) bit for metal; Sandpaper; Plumber's tape ; Wrench 80- Gallons (360 L) propane tank; Appropriate hose fittings; Ivory dishwashing liquid; 1-inch(2.5 cm) hose, at least 8 feet (2.4 m) long; 1 or 2 straight kiln shelves and spacers and Hacksaw."

Constructing the hamber

"Choose a dry, level ground for the kiln site, whether it is concrete, asphalt or hard earth. If the site is uneven, use a shovel or spade to level the ground. For concrete or asphalt, it is necessary to level the bricks with sand. It is necessary to check your work with a bubble level. The basic steps are:"

i. "Gather together the materials for the kiln. The circumference of the cylinder for the chamber is based on the size of the kiln shelves you intend to use. The shelves should be able to accommodate your largest piece. There must be 3 inches (7.6 cm) of space between the edges of the shelves and the kiln wall, it is important to calculate accurately the length of expanded metal you will need. The height of the kiln will be 24 inches (61 cm), which is equal to the standard width of fiber blanket."
ii. "Mark the sheet of expanded metal with a lumber crayon, and then cut it to the length you want with the wire cutters.
iii. Roll out the fiber blanket onto the cut piece of expanded metal. Mark and cut the blanket with the heavy-duty scissors so that it matches the length of the metal.
iv. Bend the expanded metal into a cylinder, overlapping the ends by a few inches.
v. Cut three short lengths of the nichrome wire. Use the pliers to twist the wire through the overlapped ends of the expanded metal at the top, middle, and bottom of the cylinder's seam.
vi. Line the chamber with the fiber blanket; it is okay if the fiber overlaps itself a bit. Align the ends of the blanket so that they are over the metal's seam.
vii. Secure the fiber blanket to the chamber. If you are using the anchor pins, put a 3-inch (7.6 cm) square of fiber blanket between the stud and the furrel. You will need two pairs of pliers to lock them together, whichever type of fasteners you use, position them every 12 inches (30.5 cm) or so around the

top, the center, and the base of the chamber. Cover the seam in the blanket with a 2-inch-wide (5 cm) strip of fiber blanket.

viii. Use scissors to cut a burner port or hole 2 inches (5 cm) from bottom edge of the cylinder. The burner port should be 2 inches (2.5 cm) larger in diameter than the burner unit.

ix. On the opposite side of the cylinder, midway up the wall, cut a peephole 3 inches (7.6 cm) in diameter.

x. The kiln lid's circumference should be slightly larger than the diameter of the cylinder. Cut the expanded metal into a cycle, then cut a 3-inch (7.6 cm) flue hole in the center of it.

xi. Place the lid on top of the fiber blanket. Since the lid is slightly larger than the maximum width of the blanket, cut two half-circles from the blanket. Use a utility knife to trim a ledge into the straight edge of one of the half-circles, so that the two pieces can overlap, fitting neatly together.

xii. Attach the two handles to the lid, but close to one edge rather than exactly flanking the flue hole. Secure the fiber blanket to the lid as described in step 7. Cut the fiber blanket away from the flue hole.

xiii. Make a plug for the peephole out of fiber blanket. Cut the fiber 4 inches (10.2 cm) wide. Determine the length by rolling it up until it is big enough to fill the peephole. Wrap the fiber plug with refractory wire near each edge and in the center. Cut and flatten the wires' ends so that they wound not catch on the edges of the peephole."

At the end of the construction, the kiln was fired to a temperature of 1160^0C and was able to casein shells of different sea animals and used for preparation of local glaze. The use of this kiln also brings the knowledge of waste to wealth, in that these shells are used to produce glazes that fit into the ceramic industry.

Conclusion

Kiln technology is very old. The technology of its development commenced from a simple earthen trench filled with pots and fuel known as pit-firing, to more sophisticated modern methods, which usually occurred in various processes in stages. One improvement was to build a firing chamber around pots with baffles and a stoking hole. However, with the industrial age, kiln design gradually transformed to the use of electricity and more refined fuels, including natural gas and propane. Many large industrial pottery kilns made use of natural kerosene, as it is generally clean, efficient and easy to control. Kerosene kilns are the most popular type of fuel kilns used today.

The kiln is an insulating and refractory fire chamber that has the ability to retain the heat that is generated into it and utilizes such heat in baking the ceramics and pottery wares in the chamber to the desired temperature. Kiln is also a thermally insulated chamber; a type of oven that produces temperatures sufficient to complete some processes, such as the drying, chemical changes and hardening (Adetoyinbo, 2006). Umoh (2018) states that ceramics wares in their green ware state are not accepted as finished works without firing. Therefore, firing determines the success or failure of any ceramics practice. Ceramic industries and related industries use kilns to harden objects made from clay into pottery wares, water closet system, tiles and bricks. While other allied industries use rotary kilns for pre-processing to culminate ores, cement, lime and many other materials.

The end product of the kiln isn't just for beautification, it is used to transform waste to wealth.

Recommendation

The research therefore recommends that:

a. Various units of the Fine Arts Department should venture into production of Equipments as to control the excess waste littering our environment causing hazards.
b. The government should assist various industries in the manufacturing of Equipment for recycling the waste they turn out.
c. every organization should venture into into transforming the waste they turn out into producing a different item or commodity to be used in the society.

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