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Rethinking Heat Energy in the Conversion of Clay to Ceramic: A Key to Successful Ceramic Practice

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Abstract

Ceramics as the art and science of baked clay has provided man with several wares with which man solves his daily problems. Heat or thermal energy plays a vital role in the baking, firing or conversion of clay in ceramic production as no green ware, no matter how beautiful, is useful without being subjected to heat treatment which converts clay to its permanent, rocklike, dense, vitreous, impermeable, beautiful and useful ceramic. Over the years, potters as creative people have been producing beautiful wares only to lose a lot of them during firing as a result of lack of adequate knowledge of the action of heat energy in the conversion process. The aim of this paper therefore is to bring to the fore, the action of heat energy in the conversion of clay to ceramic. The objectives will include; to take a look at what a kiln is, to consider the types of kilns, the sources of energy for firing kilns and the approaches towards achieving a successful firing. Data are collected from both primary and secondary sources which will give a better understanding of heat energy and its role in the conversion process.

Keywords: *Energy, Kiln, Baking, Conversion, Vitreous*

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Background to the Study

Ceramics is one of the earliest crafts invented and practiced by man for the provision of the needed house hold utensils to solve human problems, thereby making human settlement convenient. Microsoft Encarta (2009), defines pottery as "Clay that is chemically altered and permanently hardened by firing in the kiln. The nature of pottery therefore is determined by the composition of the clay and the way it is prepared; the temperature at which it fires and the glaze used. In achieving this important task, the natural elements namely, the earth, water, air, sun and fire have been involved in the entire process of ceramic production. The earth provides the clay-x, coal, wood, crude oil and its attendant products, the water aids transportation, decomposition, fermentation, plasticity and malleability, the air helps in evaporation which changes the clay from wet state through leather hard state to bone dry state, the sun produces the heat energy that does the work of drying and preheating and the fire supplies the heat energy for the conversion of the clay to ceramic. Ceramics as practiced in every part of the world was not only discovered in or confined to one place but the malleable nature of the material, clay informed its usage, tools, equipment and firing in every culture at different times. Udoka (2012), said that "the idea of firing clay vessels must have been discovered by accident during the most primitive stage of human existence". It is worthy of note that the traditional techniques of production have remained the same though with some slight changes as a result of some newly developed materials and equipment, especially in the area of industrial ceramics. The firing of wares came accidentally as a result of man's contact with fire which marked the end of the ceramic production process. From the discovery of firing, a lot has been done to develop it from the bonfire to pit kiln, single chambered kiln, tunnel kiln, updraft and downdraft kilns, their advantages and disadvantages and the different sources of energy. The fact remains that the action of heat energy is what converts clay to ceramic and the strength of a ceramic ware and thermal efficiency depend on the degree of combustion which determines the amount of heat generated, retained or confined, raised and used by the kiln.

Aim and Objectives

The aim of this paper is to accentuate heat energy in the conversion of clay to ceramic as a key to successful ceramic practice and the objectives will include to explore the use of kiln in firing pottery, to explore the supply of heat energy to the kiln, to consider the possibility of heat energy control, to identify the causes of thermal shock and to explore the possibility of averting thermal shock.

Literature Review

The necessary data for the review of related literature were gathered from primary and secondary sources.

Theoretical Framework

This study is anchored on modern creativity theory propounded by Kanematsu, H and Barry, D. M. in 2006. The creativity theory underscores the ability to improve on established ideas into new ones and to integrate new borrowed ideas into previously organized systems or situations. The theory explains ways in which new and existing ideas can be combined in different forms to meet contemporary trend. This theory goes in line with the words of Apostolos- Cappadona, (1984), that

"I am a potter, a maker of things, for my works to be good now and be better in the future requires doing. Potters are practical people with their conversations focusing on clay bodies, recipes, recalcitrant kiln problems, new technologies, new materials and yet let us be frank, sales"

This theory supports the idea of merging tradition with modernity to produce quality wares to meet modern taste, functions and demand. It is therefore relevant to this study because it serves as a tool to comprehend the importance of revisiting an existing concept on materials, tools, techniques, equipment and sales in a more creative way to meet contemporary challenges. In this circumstance, the art of clay baking which is the final and most important and fascinating stage of pottery production that determines the success or failure of the practice and thermal shock which remains the greatest reason for loss of fired wares are revisited.

The Kiln

Microsoft Encarta (2009), said that "a kiln is any of several kinds of furnaces, heated electrically or by the combustion of fuels, used to fire pottery or ceramic products, to roast ores, or in the production of cement" The kiln is an oven, specially designed and built with refractory materials to generate, raise and retain heat, high and long enough to convert clay to ceramic. Bryan (2011), asserts that "a kiln is a versatile piece of equipment in the studio". The kiln can be seen as the ceramic master and judge as it determines the success or failure of ceramic practice and exposes whatever had not been done right in the course of production. The importance of kiln and the action of heat energy on clay is stated clearly by Cardew (1977), who asserts that "clay ware, however much skill and knowledge have gone into its making, has no commercial value until it has been fired". This is supported by Hamer (2004: 85) who posits that "ceramic change is from clay to pot, upon which the whole pottery industry is founded." It is an established fact that one of the natural properties of clay is to slake or disintegrate in water and can be made into a plastic body severally when it has not yet been calcined through heat treatment in the kiln, but once it has been fired, it becomes hard and rocklike and can no longer be recycled into plastic state. Umoh (2018:44), stated that ceramic wares in their green ware state are not accepted as finished works without firing. Tam-George (2021:4), added that "it is obvious that firing is an indispensable aspect of all ceramic productions." It can be seen from the above facts that the kiln, whether the earliest bonfire method or the modern sophisticated ones which fire with solid fuels such as coal and firewood, liquid fuels such as diesel, engine oil and kerosene or natural gas and electricity, they all generate, confine and raise heat energy to the expected temperatures that converts clay to ceramic to solve man's problems.

The kiln, whether local or modern, single chamber or tunnel, updraft or downdraft is able to generate, confine and raise the heat to the expected temperature due to the refractories used for the design and construction. Refractories are materials that resist fusion at very high temperature. The two major refractories in the building of the kiln are the insulating and the dense bricks which are produced with special bodies formulated with kaolin, wood dust or straw, silica or quartz, ball clay and water. While the kaolin helps to glow the kiln faster, builds up the required temperature and resists fusion, the wood dust or straw burns out to create the pores which retain the heat by stopping the cold air from entering the kiln through the walls and the quartz or silica also resists fusion and provides the strength to the kiln.

Another part of the kiln that contributes to temperature rise and retention is the chimney which controls the draft. There is much heat loss in an updraft kiln than in the downdraft kiln. Greg (2009), asserted that "an updraft kiln receives fire at the bottom and exhausts at the top." This is due to the position of the chimney. In an updraft kiln, the chimney is on the dome and therefore does not retain much heat for proper circulation because the heat generated rises and escapes through the chimney. On the other hand, the downdraft kiln has its chimney constructed from the floor of the kiln. Elliot (2004), posits that "downdraft kilns are designed to force heat to circulate throughout the kiln chamber. Heat generated therefore is retained and forced to circulate properly before escaping through the chimney at the bottom". This promotes thermal efficiency (work done) in the downdraft than in the updraft kilns. At this point, it is worthy of note that it does not matter the type of kiln and the source of energy for firing, but that heat is generated, confined and raised to the required temperature to convert clay to ceramic to meet the needs of man in the home, building industry, fashion industry, health sector, and engineering sector, to mention but a few. The kiln can be fired under three atmospheres namely, natural, oxidation and reduction atmospheres and the ceramic materials are grouped under acidic, alkaline and amphoteric media.

Heat Energy

Anyakoha (2016:38), asserts that "heat is a form of energy called thermal energy." Heat is energy in transit perceived as temperature which is the degree of hotness or coldness of an object. Energy, according to Ababio (2016: 232), is the ability to do work and for the purpose of this paper, the two forms of energy considered are, the heat or thermal energy and electrical energy. It can be said that heat is a transferred energy that arises from the random motion of molecules and is felt as temperature, especially as warmth or hotness. It is the energy transferred from a hot object, the kiln to a cooler object, the wares as a result of their difference in temperature. In firing the kiln, the fire comes through combustion which requires the fuel, oxygen and an initiating energy or the source of ignition which must have enough energy to start the chemical reaction. In the firing of ceramic wares, heat flows from the kiln at higher temperature to the wares at lower temperature. The thermal efficiency or the work done in a firing session is determined by the degree of energy or heat supplied, retained and built up by the kiln. A poorly designed, constructed and fired kiln cannot produce a good thermal efficiency. See figure 1. On the other hand, a well-designed, constructed and fired downdraft kiln will yield a better thermal efficiency than an updraft kiln. See figure 2. Where there is an incomplete combustion, the thermal efficiency will be next to zero as the generated heat may not be enough to calcine the clay. However, an incomplete combustion can be made intentionally in what is called basting, where an already fired hot pot is dropped and turned in wood dust or other organic materials to achieve the traditional black stains finishing. See figure 3.

Figure 1: Pre-Mature Glaze
Medium: Earthenware
Artist: Kadmiel O.
Year: 2021

Figure 2: Mature Glaze
Medium: Earthenware
Artist: Umoh J. J.
Year: 2010

Figure 3: Incomplete Combustion
Medium; Earthenware (Bisque)
Artist: Umoh J. J.
Year: 2019

Transfer of Thermal Heat in the kiln

The transfer of thermal heat from a body of higher temperature to another body of lower temperature can occur in three ways namely, conduction, convection and radiation. For the purpose of this paper, only heat transferred by radiation which is most appropriate will be discussed. Anyakoha (2016: 52), says that "Radiation is the process by which heat is transferred from a hotter to a cooler place without heating of the intervening medium." The thermal heat transferred in the kiln is called, radiant heat or radiant energy. The wares to be fired are placed in between the bag walls, away from the fire ports or the elements in the case of electric kiln, before the heat is introduced to the kiln. The temperature or work done inside the kiln is measured with thermocouple, pyrometer or pyrometric cone. These instruments are used for measuring very high temperatures by converting brightness, radiation or electric current measurements into temperature reading usually in degree Celsius or degree Fahrenheit.

Effects of Heat on Ceramic Wares

Kiln firing is a very fascinating and important aspect of ceramic practice. This is because during the firing session, a lot of things take place inside the kiln while the ceramist waits patiently for the result. Due to the fact that the kiln determines the success or failure of the entire production process, the ceramist must do all that is necessary to yield the best result. The desire to have a successful practice has revealed that there is more of science in ceramics than art. While it is art to conceive and create the forms, science is involved in the formation of rocks and clay, it's components, contaminants, properties, preparation, body formulation, fluxing agents, oxides, refractories, compounding glazes and engobe, glaze behaviors, defects and remedies, fabrication of equipment, study, design, construction and firing of kilns and so on. The reason to acknowledge the role of science in ceramics therefore, is to ensure successful practice.

Below are some effects of thermal or heat energy on ceramic wares.

Thermal Expansively

Solids expand or increase in size when heated and contract or reduce in size when cooled. The expansion of wares is reversible while the contraction is irreversible. When heat is supplied to the kiln, the wares inside expand, this knowledge is applied when placing wares for firing. Though wares for bisque firing can touch themselves, it is advisable to allow one or two centimeter space around the wares, especially if they are placed for glaze firing. This is to avoid the wares being fused together by melting glazes. In some cases, large and heavy wares are placed on silica (sand) spread on the kiln shelf to serve as rollers during expansion.

Since different objects possess different expansion rate otherwise referred to as coefficient of expansion and different shrinkage or contraction rate when subjected to heat, the ceramist must chose his materials wisely when formulating the bodies to work with. This becomes very necessary because using materials with different expansion and shrinkage rates on the same work will create serious problems. Two clay bodies with different expansion and shrinkage rates must not be used in one ware else they will reject themselves, causing damage to the ware during drying and firing. In the same way, glaze with high shrinkage rate cannot be used on a clay body with low shrinkage rate else, the glaze will continue to shrink or contract when the clay body it covered had stopped shrinking. This will cause a glaze defect known as crazing.

Change in the Physical Properties

The action of heat on clay will cause changes in its physical properties. When heat is applied to clay, there will be a change in colour, the clay will shrink a second time and will no longer be plastic because it has been calcined. The heat also burns out the carbonaceous contaminants in the clay thereby making it more porous for easy circulation or migration of heat which ensures successful firing.

Change of State

The supply of heat to clay will change its state to a rocklike, dense, vitreous, impermeable and durable states.

Chemical Change

The action of heat on clay and other ceramic materials such as metallic and non-metallic oxides, engobe and glazes brings about chemical changes such as fusing and melting which result in the final beautiful bisque and glazed wares. It is the action of heat on silica, the glass former that creates crystabolites on the surfaces of the wares to accept the glaze. Heat energy also changes the alpha particles of clay to beta particles in what is known as 'quartz invasion'. This is a point in firing where higher temperature, after burning out clay contaminants causes the clay particles to begin to fuse thereby making the wares dense, vitreous and impermeable with advancing temperature. This fact is supported by Okoli (2021), who posited that "vitrification is a progressive fusion of ceramics substances as the temperature increases. This vitreous nature of wares as a result of very high temperature makes the wares resistant to scratches and corrosion and therefore useful as electrical insulators, floor tiles, laboratory vessels, and for the lamination of electrical appliances, to mention but a few.

In a process known as fritting, some soluble and very poisonous but useful fluxing agents such as lead and borax are stabilized by melting them with silica, dropped into cold water to shatter as a result of sudden change in temperature and ground into insoluble powder which is no longer poisonous.

Thermal Shock; causes and effects.

Thermal shock refers to the stress in a body caused by rapid and sudden changes in temperature, often resulting in disasters or fractures. A ceramist must do everything necessary from his choice of clay and other materials to firing to avoid thermal shock which is usually triggered by error in the production line.

Thermal shock can be caused by many factors including the following.

a) Firing a piece that has not given off completely, its water of plasticity to become bone dry.
b) Firing a body that had trapped air in the course of preparation and modelling.
c) Where there are modelling faults such as, poor joining, excessive thickness and weight, use of different clay bodies with different coefficient of expansion and contraction in one ware, not formulating a stress resistant body and not providing enough opening or outlet for the heated air in the ware to freely escape. See figure 4 a and b.

Figure 4a: Peeled Vase(Dunting)
Medium: Glazed Earthenware
Artist: Kadmiel O.
Year: 2021

Figure 4b: Fused Fragment from Fig 4a
Medium: Glazed Earthenware
Artist: Kadmiel O.
Year: 2021

d) Not preheating wares long enough before full blast firing.
e) Not raising the temperature gradually. In other words, firing the kiln too rapidly.
f) Closing the vent and spy hole too early into the firing session thereby stopping harmful materials such as water, sulphur (sulfur) and calcium carbonate from escaping early. The temperature must be taken gradually to about 750 degree Celsius before closing the vent and the spy hole for full firing session.
g) Where gas is used as the source of energy for firing, the burners must be lit and fine-tuned before inserting into the burner ports. In a case where there is gas leakage into the chamber, measures must be taken to expel the gas completely before lighting the burners. If this is not done, the entire chamber will be lit the moment the lighter is struck and the sudden vibration and change in temperature will be disastrous.
h) When the firing session is over, the kiln must remain closed for about the same period taken to fire it or more. The slow cooling allows the glaze to mature properly and be glossier while the kiln returns gradually to the normal temperature that the wares can be touched with hands. If the kiln is opened immediately after firing, the cold air

outside will rush into the hot kiln thereby causing a sudden change in temperature and this will not only be disastrous to the wares but also the kiln and the person who opens it. The thermal shock will affect the kiln walls, the wares will shatter and the pieces will fly out of the kiln door against the potter.

i) Another area in firing where thermal shock can cause great disaster is when the gas finishes from the cylinder while the burners are still on without being immediately removed. The cylinder sucks back the hot air from the chamber and the resultant explosion does not only damage the wares but the entire kiln, human lives, studio and the environment.

Conclusion

From its birth, centuries ago, ceramics as one of the oldest crafts has been in the business of creating and providing a wide range of wares to solve human problems in material deposits. The fact is that there would not have been ceramics without the action of thermal heat to convert clay to ceramic. The knowledge of the action of heat in the conversion of clay has brought to the fore, the place of science in ceramic practice. The ceramist therefore must understand that to have a successful practice requires proper knowledge and choice of materials to formulate a ceramic body that can go through the firing session without fracture and a proper control of a functional kiln.

It is a known fact that ceramics is experimentation where the good, the bad and the ugly can shoot out, therefore the ceramist must have adequate knowledge of his materials, techniques and equipment to ensure the success of his practice. He must have a good knowledge of the kiln, its types and firing atmospheres such as natural, oxidation and reduction and the media of the materials such as acidic, alkaline and amphoteric.

Finally, the paper has re-emphasized the importance of thermal or heat energy in the conversion of clay to ceramic and some factors that can cause thermal shock which usually leads to loss of wares and failure in the practice.

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