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A REVIEW OF TRENDS AND DEVELOPMENTS IN CERAMIC FUELS AND APPLICATION OF BIOGAS IN CERAMICS KILN FIRING IN NIGERIA

Ezra Abubakar
Department of Industrial Design,
Modibbo Adama University of Technology, Yola
ebubakar@gmail.com,
Y.O. Sadiq
Department of Industrial Design,
Abubakar Tafawa Balewa University, Bauchi

Abstract
Tremendous changes have occurred in the use of ceramic fuels; beginning from when grass/leaves, wood and cow dung were used in open bonfire to the period when advances in science and technology made possible the introduction of sophisticated firing techniques and procedure, as well as the adoption of efficient and sustainable firing fuels. This reviewed article, reviews the development of ceramics fuels and firing technology in Nigeria; the drawbacks of traditional ceramics fuels and the driving force for the shift towards sustainable alternative fuel for ceramics kiln firing. The article also looks at the historical development of biogas as clean and renewable source of energy, its application to ceramic kiln firing as well as the current stage of research into biogas as ceramic fuel in Nigeria.

Key Words: Biogas, Fuel, Firing, Alternative, Sustainability, Development

Definition of Technical Terms
AD: A series of biological processes in which microorganisms' breakdown Biodegradable materials in the absente
BAT: Best Available Technology
Bonfire: Firing ceramics in open surface
Bisque Firing: First firing at lower temperature to make pottery less fragile
Crankcase oil: Waste/used engine oil
Digested: The solid and liquid material that remains at the end of anaerobic digestion process
GCM: Gas Chromatography Machine
IPPC: Intergovernmental Panel on Climate Change
LPG: Flammable hydrocarbon gases used as heating, cooking and auto fuel
Kiln: Thermally insulated chamber used for dry, hardening or chemical changes
Siloxanes: A class of compounds containing alternate silicon and oxygen compounds
UNASCP: United Nations Agenda for Sustainable Production and Consumption

Introduction

Prior to the advent of a 'closed' structure called kiln, ceramic wares were fired in open spaces; later on, trenches were constructed and used for firing; with wood, leaves, grasses, cow dung and all manner of biomass used as firing fuel. However, the introduction of the engineered structure; kiln as a ceramic firing system opened the way for the use of more specialized ceramic firing equipment (Burners) and variety of fuels such as Crankcase oil, Coal, Liquefied Petroleum Gas, Kerosene, Electricity, hence the elimination of leaves and grasses (Goyer, 2006). Although these fuels have been used to fire ceramics in kilns to higher temperatures (stoneware), this is not without human and environmental consequences; as reports have indicated that hundreds of tons of carbon dioxide ($C0_2$) are emitted yearly into the climate system from the use of these fuels (Peng, Zhao, Jiao, Zheng, and Zeng, 2012). More so, some of these fuels cannot be relied upon due their epileptic nature. The short fall of these fuels necessitates research into accessible and sustainable alternatives such as solar panels, biodiesel, biogas and human powered batteries as sources of energy for ceramic kiln firing (Shippensburg University, 2017). The accessibility and abundance of biomass (cow dung) as well as its low sulfur content makes it popular and widely acceptable. Although, this source of fuel has been generated from a variety of sources (landfills to bioreactor) and applied to a variety of uses with great success recorded; its application to ceramic kiln firing system is only a recent development. The article therefore discuss the developments made in the use of ceramic fuels and their drawbacks, the historical development of biogas and the drive towards the use of biogas as sustainable alternative fuel for ceramics kiln firing

Historical Development of Biogas

The flammability of gases generated from decaying organic matter was first established in 17th century by Jan Baptista Van Helmont (Abdulkarim, 2017). However, prior to that time, the earliest use of biogas for utilitarian purpose such as its application for heating bath water has been traced to the Assyrians from about 3000 years ago (Ali, Zahra, Nasreen and Usman, 2013). More so, the generation of biogas from sewer has also been documented by the Chinese some 2000-3000 years ago (Kumar, Mandal and Sharma, 2015). However, the relationship between the quantity of biodegradable matter and the flammability of the generated gas was established by count Alessandro Volta (Deepanraj, Sivasubramanian, and Jayaraj, 2014), and the existence of methane as one of the components of the anaerobic digestion of cow dung was discovered by Sir Humphrey Davy in 1808 (Deepanraj, Sivasubramanian, and Jayaraj, 2014; Kumar, Mandal and Sharma, 2015).
Nevertheless, as the understanding of the science and technology behind anaerobic digestion process and the design of reactors became advanced and popular around the world; biogas generating plant began to spring up with the first plant built by Indians in Bombay (Lusk and Moser, 1996). Years later, the Indian model was adopted in England and used as a source of energy for lighting street lamps (Kumar, Mandal, and Sharma, 2015), the management of sewage in United Kingdom and Germany and as a source of vehicular fuel particularly during the World War II (Deepanraj, Sivasubramanian, and Jayaraj, 2014).
Thousands of households across the globe depend on biogas for their source of energy with a vast majority of these users domicile in Asia (Abasi, Tauseef and Abasi, 2012; Nguyen, Haven and Banks, 2014). Although the exact figure for the global total biogas production is unknown, an estimated value was put at between 300 and 400 Tera Watt (TW) and the total global substrate potential for biogas production to 10,000 Tera Watt Hour (TWH) (International Gas Union, 2015). The recognition of biogas as a fuel with the potential to meet the energy requirement of Africa is gradually gaining momentum as evidenced by the installation of biogas plants across the continent aimed at providing energy to households and small businesses. The Ibadan biogas plant for example is one of the largest plants in the continent designed and targeted to provide energy for 5,400 households (Brown, 2006).

Solid Fuels

Prior to the development of kilns, open bonfire and clamp methods of firing using fuels such as dry leaves, wood, cow dung, saw dust, rice husk, and coal, for firing ceramic wares were most common (Gosselain,1992; Smith, 2001; and Festus, 2009). The advent of kilns meant that, the potential heating value of these solid fuels could now be maximally utilized for the attainment of high cone temperature. Although the precise date to indicate when solid fuels (sawdust, rice husk, leaves, and cow dung) were first used for ceramic firing in Nigeria cannot be ascertained; the application of wood firing technology to ceramic kiln is traced to the attempt of David Roberts in 1904 in Ibadan, Nigeria (Festus, 2009). This giant stride, made by the British potter to fire a ceramic product using wood marked the beginning of modern ceramics and opened up the way for the adoption of the wood firing technology by the Okigwe and the Ladi Kwali Pottery Centers both established in 1950 and 1951 in Imo and Niger State respectively (Onuzulike, 2016). However, Ceramicsartdaily, (2009) posits that, in spite of the prominent role played by solid fuel to the development of ceramics, and its spectacular characteristics of exhibiting a visual, irregular and 'unpredictable' aesthetic patterns, particularly when alkaline and ash from the solid fuel fall on the ware (bisque or glaze), which is a major attracting point for most solid fuel enthusiast; there are however, some setbacks associated with its use. For example, the use of wood for kiln firing is physically demanding- as the fire box needs to be stoked continuously in a controlled manner. There is also the issue of constant removal of burned ashes (Ekong, 2013; Ceramicsartdaily, 2009). Wood also requires large volumes and areas for storage, it needs to be delivered to the kiln site and must be kept dry (Ceramicsartdaily, 2017). There is also the concern over gas vapour released from wood and the alkali contained in wood ash, which have been found to fuse with cones resulting in low melting temperature of pyro metric cone (Ekong, 2013). However, in spite of the numerous disadvantages of firing ceramics using sold fuels, their proximity to potters in rural areas (traditional potters) as well as the non-requirement of any technical 'know how' in the use of these fuels for ceramics firing means that; their use as a source of energy for ceramic firing in rural areas will continue. We also expect to see continuity in the use of solid fuels singly or in combination (fuel mix) with other fuels for ceramic firing in urban areas

Liquid Fuels

Liquid fuels such as kerosene, spent oil and diesel oil also known as crankcase, or waste engine oil have been used successfully to fire ceramic kilns up to cone temperature of 1280^{0}C. The introduction of spent oil to ceramic kiln firing was credited to David Clark in 1985 (Ahuwan, 2017). Clark's attempt provided the basis for future research and data building on the use of oil for ceramic firing. Following from Clark's attempt were Yusuf Ottaru Sadiq, who also experimented on the use of spent oil for ceramic kiln firing and Datiri Yohanna who also fired ceramic kiln with both spent and diesel oil (Datiri, 1998). Furthermore, Kenneth Eweka in 2009, also fired ceramic kiln to a bisque and glaze temperature range of 8000C - 960^0 C, and 1050^{0}C-1250^{0}C respectively (Eweka, 2009). Successful large scale application of spent oil for kiln firing was also evidenced in the operational years of Mararaba Pottery, Mararaban Jos, and Kaduna State until its closure in 2012.

The pioneering application of kerosene as a ceramic fuel was traced to Yusuf Ottaru Sadiq; when in 1989, he used a mixture of kerosene and water acting under gravitational force to fire ceramic kiln at the Department of Industrial Design, Ahmadu Bello University, Zaria (Sadiq, 1990 and Festus, 2009). He also made improvement on the use of kerosene for ceramic firing by eliminating water and the effect of gravity; by introducing pressure into kerosene tank and deploying it to fire ceramic kiln up to 1280^{0}C (Sadiq, 1990 and Sadiq, 1996): - a practice which is still in use today in many pottery studios, ceramics centers and institutions of learning across the country. Following in the footstep of Yusuf Ottaru Sadiq was Sanusi Abdulkadir, who also worked on ceramic kiln firing using pressurized kerosene (Ahuwan, 2017). Despite the recorded successes on the use of liquid fuels for ceramic kiln firing, there are some drawbacks associated with their use. An example of the downside to the use of spent oil, for example is the difficulty in keeping the oil lit until the temperature is above 538^{0}C (Ceramicsartdaily, 2009). It is also known to cause cracking and sagging effect on kiln walls as well as being a potential for fire hazard (Ekong, 2013 and Ceramicsartdaily, 2009). Similarly, the use of kerosene for firing ceramics kiln also require constant pumping of pressure into the kerosene cylinder which is physically demanding and tiring. Firing ceramic kiln with these fuels also require patience and technical expertise, particularly when locally fabricated burners are used for the firing. More so, given that waste oil is now being paid for (it is previously discarded as waste) and the price of kerosene is on the increase; accessibility and availability must therefore be considered when proposing the use of these fuels.

Liquefied Petroleum Gas (LPG)

The pioneering application of liquefied fuel to ceramic kiln firing in Nigeria was dated to 1985; when David Clark produced and successfully fired a small gas to 1230^{0}C (Ahuwan, 2017). James Ewule was also reported to have experiment with gas kiln and facilities in 1988 (Ahuwan, 2017). Although, the use of liquefied petroleum gas for ceramic firing predates the use of pressurized kerosene, the lack of technical expertise on kiln firing using gaseous fuel coupled with the non-availability of specialized burners at the initial stage of its development, limited the acceptability and growth of the technology (Festus, 2009). However, the breakthrough in the use of gaseous fuels for ceramics kiln firing came with the discovery and the understanding of the technicalities involved in firing gas kilns such as the design and construction of burners to fit in with the requirement of gaseous fuels, proper handling of the gas burners and the stoichiometric requirement (proper mixture of fuel and oxygen) which is essential for efficient combustion (European Commission, 2007). It is worthy to note however that, burner handling and the ability to maintain a stoichiometric relationship between air and fuel require good firemanship skill; especially when firing with non-standard burners (Local burners). Equally butane and propane are volatile and highly flammable gases; therefore, to safe guard against the dangers of explosion and fire hazards caution must be exercise when firing with these fuels.

Electricity

This form of energy cannot be relied upon in Nigeria for ceramics firing due to its epileptic supply (Etuoke, 2013) and the continued increased in tariff. For example, the variation between the current Multi Year Tariff Order (MYTO 2) which replaces MYTO 1 require electricity consumers in different locations and categories to pay different charges for the same kilowatts of electricity (National Electricity Regulation Commission, 2016). The non steady and erratic supply of electricity in Nigeria is a limiting factor for the use of this source of energy for industrial ceramic production and is believed to be responsible for under production, closure or relocation of ceramics industries from Nigeria to the other countries (Ghana) were the supply of electricity is guaranteed.

Aim of the Article

The aim of this article is to assess the progresses made in the use of ceramic fuels, the application of renewable alternative fuel to ceramic kiln firing and the current state of biogas research in ceramic fuel in Nigeria

Main Thrust of the Article

Biogas

Biogas also known as 'deep green gas' and classified as biofuel is a renewable source of energy; produced naturally from the decomposition of organic matter such as animal waste, municipal solid waste, sludge from waste water treatment plant and food scrap under anaerobic (oxygen free) condition (Benzaken, 2017). The decomposition process which normally occur in an Anaerobic Digestion (AD) reactor, results in the generation of a mixture of gases containing primarily methane (CH_4), and carbon dioxide ($C0_2$), with some trace amounts of hydrogen sulphide (H_2S), moisture and siloxanes (Bio2waste, 2016). The AD condition required for the generation of biogas is created by the use of specially designed reactors such as the fixed dome and floating digesters. The production of biogas through AD processes (Hydrolysis, Acidogenesis, Acetogenesis, and Methanogenesis) has the following advantages: it is a carbon neutral technology with the potential to provide energy for both large and small scale industries. It is used as a medium for treating and converting waste into energy: a suitable alternative to fossil fuel. Biogas also has the potential to reduce environmental impact of air pollution and the amount of waste going to landfill. Similarly, digested from the AD process can be used as a nutrient rich source of manure on farms and garden: contributing to sustainable agriculture and forestry (Bio2waste, 2016).

Application of Biogas as Alternative and Sustainable fuel for Ceramics Kiln Firing

Biogas is considered clean, and an environmentally friendly source of energy (Weiland, 2010); and for hundreds of years, this gas has been used as a source of heat and power for utilitarian purposes. Biogas has also found applications in both small and large scale industries globally as a suitable source of sustainable and eco-friendly fuel. Currently biogas is used to supplement electricity supply in some developed countries of the world like Austria, Germany, and Sweden by feeding it into distribution power lines (Weiland, 2010). However, the concept of exploiting and use of biogas as a green, renewable and sustainable source of alternative energy for ceramics kiln firing is a recent development, with only a handful of documented evidence available (Sadiq, 2004, Ayats, Jimenez, and Cabre, 2007).

The earliest documented application of the technology to ceramic kiln firing was reported by Sadiq (2004), the experiment which was carried out at Abubakar Tafawa Balewa University, Bauchi; Nigeria marked the beginning of a shift towards the use of cow dung generated biogas for ceramic kiln firing. A similar application of biogas derived from an active landfill for application to ceramic kiln firing in Spain has been reported by Ayats, Jimenez and Cabre (2007). Biogas generated from closed landfill was also used to fire ceramics kiln in EnergyXchange Burnsville North Carolina, USA (Harnetty, 2010). However, it is also pertinent to state that, all the previously documented applications of biogas technology to ceramic kiln firing were based on the use of un-scrubbed (raw biogas) biogas. This limits the firing temperature to a range of 700^0C - 900^0C which is below stoneware/ porcelain temperature (Sadiq, 2004)

The application of biogas for ceramic kiln firing was based on the discovery of its intrinsic potential to provide the heating needs of households across the globe (Munchiri,Wanjili, Hinga and Kahiu, 2012), its ease of control and handling, as well as savings in terms of time, and energy (Abubakar and Gausa, 2013). Biogas is also shown to be cost effective (Table 1), as it could fire a ceramics kiln up to bisque temperature with N500 worth of fuel (Sadiq, 2004). Comparing this with kerosene, firing expenses are 5 times more costly; with butane and natural gas, they are about 8 times and with firewood about 3 times more (Sadiq, 2004). However, for biogas to be used for ceramic kiln firing it needs to be compressed into canister/cylinder, (the pressure of biogas coming from digester is not enough for direct application to kiln firing). Compressing biogas into cylinder is a technical procedure that is risky and requires adequate training and experience. Therefore, for efficient use of this technology particularly in rural areas (by local potters), training is essential. Furthermore, the size of kiln to be fired and the firing temperature (anticipated temperature) shall depend on the availability, quantity and quality of the generated biogas.

A summary of the biogas application to ceramics kiln firing, the calorific value of biogas with varying methane content and the energy content of biogas are shown in tables 2, 3 and 4 below.

Table 1: A Comparison of Biogas, Kerosene, Butane, Firewood and their Relative Energy Cost

Fuel	BTU rating/cu.Ft	Estimated fuel consumption	Cost/quantity N	Cost/firing/remark N	Relative % cost
Biogas	650BTU/CF	Appr.22.3m^3	-	N500(1gln. Petrol/pumping/others)	100%
Natural gas	1150 BTU/CF	Appr.25kg	N4,500/25kg cylinder	N4,500	Appr.900%
Butane	3,280 BTU/CF	Appr. 25kg	N4,500/25kg/cylinder	N4,500	Appr.900%
Kerosene	1110 BTU/CF	Appr. 40 liters	N300/gallon	N3,000	Appr. 600%
Firewood	3,700 Cal/g	Appr. 100kg	N20/kg	N2,000	Appr.400%

Source: Sadiq (2004) based on estimated fuel consumption to fire a 4.5 CF kiln to cone 010. [Prices are unofficial rates, in 2003]

Table 2: Summary of Biogas Application to Ceramic Kiln Firing

Researcher (s)	Method (s)	Reactor	Year	Place	Substrate	Temp(^{0})
Harnetty and Baker	AD	Landfill	2008	USA	MW	700
Ayats, Jimenez & Cabre	AD	Landfill	2007	Spain	MW	900
Sadiq	AD	Reactor	2004	Nigeria	WCD	900

Source: Author's Field Work, (2016). AD= Anaerobic Digestion, MW= Municipal Waste, WCD= Wet Cow Dung

Table 3: Biogas Calorific Power Depending on Biogas Content

Methane Content (%)	Calorific value (kcal/m^3)		Methane Content (%)	Calorific value (kcal/m^3)	
	At 0^{0}C and 760mmHg	At 20^{0}C and 760mmHg		At 0^{0}C and 760 mmHg	At 20^{0}C and 760 mmHg
50	4281	3955	66	5650	5261
52	4452	4145	68	5822	5420
54	4623	4304	70	5993	5579
56	4794	4463	72	6164	5739
58	4965	4623	74	6335	5898
60	5137	4782	76	6507	6058
62	5308	4942	78	6678	6217
64	5479	5101	80	6849	6376

Source: Dobre, Nicolae, and Matei (2014)

Table 4: Energy Content of Biogas Compared to Other Fuels

Fuel	Energy content (KWh)
1Nm^3 Biogas (97% methane)	9.67
1Nm^3 Natural gas	11.0
1 liter of petrol	9.06
1liter of diesel	9.80
1 liter of E851	6.60

Source: www.biogasportalen.se cited in International Gas Union (2015)

Drive for the use of Alternative Fuel and Sustainable Patterns of Production

Mining of ceramic raw materials and the firing of ceramics kilns are two (2) aspects of ceramic production process that have been reported to have impact on the environment (Ceramicsartdaily, 2009). For example, the mining of ceramic raw materials and cutting down of trees for use as fuel for kiln firing has been linked to damages on soil structure, interference with ecological system and the destruction of flora and fauna and a significant contributor to desert encroachment while the transportation of the raw materials to production sites either by sea, air or land have been linked to the emission of greenhouse gasses into the climate system-contributing to global climate change (Harnetty, 2010).

Similarly, an estimated 2 million deaths are reported to occur annually from exposure to an estimated 18000 tons of $C0_2$ emitted yearly into the global climate system from ceramics processing and firing using biomass (solid fuels) and liquid fuels (Peng *et al,* 2012). Furthermore, the calcinations of carbonates contained in clay and shale has also been indicted with contributing 20-50% $C0_2$ emission into the climate system (Intergovernmental Panel on Climate Change, [IPCC] 2007). This is a major issue of concern to ceramic professionals' researchers, ceramics fuel enthusiasts and stakeholders in the global environment and serves as the drive for the shift towards the search and use of alternative and sustainable source of fuel for ceramic kiln firing. Similarly, conforming ceramics processing and production (inclusive of sourcing and transportation of raw materials) to Best Available Techniques (BATs) and the United Nations Agenda for Sustainable Consumption and Production (UNASCP) is also a driving force to reducing the effect of the current unsustainable pattern of ceramics processing, production and firing.

Having shown therefore, that reduction in toxic emission and adapting ceramic production and firing to UNASPC and BATs concepts are the global driving forces towards the use of renewable energy for ceramic kiln firing; the challenge therefore is how to adopt to these concepts in the face of inadequate environmental regulatory framework and enforcement capabilities, existing currently in Nigeria.

Current State of Research into Ceramics Fuels in Nigeria

In a quest to have full control of ceramics firing regime, and to attain high firing temperature using fuels that are more efficient, sustainable, eco-friendly options with little or no emission of toxic substances into the environment; researchers have to focus on either improving the heating value existing in green fuels or the exploration of new ones. An example of a novel research on the exploration of sustainable source of fuel for ceramic firing is an experiment carried out on the use of biodiesel as renewable fuel for ceramic burners and kiln at Shippensburg University Pennsylvania, USA in 2017. The biodiesel used in the experiment was derived from the processing of vegetable waste oils sourced from the University cafeteria. The result of the experiment indicated that, a 30 cubic foot cross chamber kiln can successfully be fired to cone 10 (2381^0F) in 8 hrs. using 20 gallons of biodiesel fuel (Shippensburg University, 2017). Another approach to the exploration of sustainable alternative fuel for ceramic kiln firing was the reported use of human ridden bicycle to charge batteries that would power blowers and burners for ceramic kiln firing (Shippensburg University, 2017) and the investigation on the use of solar panels to provide solar energy for ceramic kiln firing (Miller, 2016). Although the long term benefits of using solar energy outweigh the cost of installing the panels; small scale pottery centers in Nigeria may not venture into it due to anxiety over installation cost. Raw biogas has also been explored as alternative energy source for ceramic kiln firing with firing limited to bisque temperature (900^{0}C) due to the presence of impurities; which are known to lower the calorific/heating value of the gas.

Research trajectory into the application of renewable energy for ceramic kiln firing in Nigeria is currently focused on maximizing the heating potentials of biogas by enriching its methane content through the scrubbing (removal of impurities) of contaminants such as carbon dioxide ($C0_2$), hydrogen sulphide (H_2S) and moisture (H_20) contain therein; with a view to increasing its calorific value for high temperature ceramic firing. However, the scarcity of standard biogas analytical instruments such as gas chromatography machine, the lack of gas collection apparatus (gas bag), and deficient technical expertise in manning some of the available gas analysing equipment is threatening the quality of biogas research in Nigeria. For example, biogas analysers found in Ahmadu Bello University (ABU) Zaria, and the National Center for Energy Research and Development (NCEDR) Nsukka, Kaduna and Enugu state respectively are unable to identify hydrogen sulphide (H_2S): a component of biogas while the only functional GC machine in North Eastern Nigeria (Yobe State University) lacks competent hand in biogas analysis. These factors are surely 'clogs in the wheel' of renewable alternative energy (gaseous fuels) research in Nigeria.

Conclusion

The setbacks of solid and liquid fuels, inadequate and erratic supply of electricity as well as the discrepancy and inconsistency in billing provided the impetus for the search into alternative sources of energy. The accessibility, environmental friendliness and the cost effectiveness of biogas in comparison to solid and liquid fuels makes it an ideal alternative fuel for ceramic kiln firing. Although the use of biogas for ceramics kiln firing is at infant stage, with research currently focused on scrubbing the gas for higher temperature firing; the adoption of biogas among other eco-friendly, renewable and sustainable fuels will play a key role in reducing the amount of toxic emission into the climate system; leading to reduced exposure and fatalities associated with the use of traditional ceramics fuels.

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