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DESIGN AND DEVELOPMENT OF CERAMIC POUR FLUSH SQUAT PAN FOR SUSTAINABLE WATER USE AND ENVIRONMENTAL HYGIENE

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Introduction

The provision of affordable housing, portable drinking water and sanitation facility such as toilets is a basic requirement of the Sustainable Development Goals target 6. Increasing population, poor governance and the rising level of poverty however, appeared to be militating against access to these basic amenities in most communities in Africa, especially Nigeria. The non-availability of sanitation facilities in schools, homes and public places is responsible for the high rate of open defecation (UNICEF, 2015, UNICEF, 2016) and increased cases of diarrhoea among adults and mortality among children as a result of ingesting contaminated food and water (Federal Ministry for Water Resources, 2018).

In the few places were public sanitary facilities are found, the volume of water required to flush and keep the facility clean combined with water scarcity have impaired their use. Given the increasing pressure on water arising from the rapidly growing population and the threat of climate change, the need for sustainable water use is evident. In view of these, high tech water efficient toilet systems such as the dual flush system have been produced to replace the non-efficient single flush system which require up to 9 litres of water per flush. Nonetheless, the high cost of these systems couple with the rising level of poverty in Nigeria means that, these systems are out of reach of most Nigerians especially those in the rural areas.

It is against this background, that this study was designed with the objectives of developing a cost efficient, affordable and water efficient Pour Flush Squat Pan toilet to curtail the economic, environmental, social, and health consequences of open defecation as well as boost Nigeria's target of ending open defecation by 2025.

Current State of Open Defecation in Nigeria

Open defecation is a major social issue in Nigerian that is impacting negatively on human health and the environment. With more than fifty million of Nigeria's population practicing open defecation, Nigeria is ranked third globally in open defecation (Federal Ministry for Water

Resources, 2018). The driver to open defecation in most urban and rural areas of the country has been linked to lack of adequate sanitary facilities (Federal Ministry of Water Resources, 2018).

The available data on open defecation across the country indicate conflicting figures, for example, data from National Demographic and Health Survey (2003) reveal that, roughly 18% of households use improved sanitation facility such as flush toilet, while 56% and 26% use traditional pit latrines and practice open defecation respectively. The same source also reveals an increase in household's use of improved sanitation facility and open defecation to 30% and 29% respectively and a decrease in the use of traditional latrines to 37%.

Despite the discrepancies in these data, the general consensus is that, there is a decline in access to improved sanitary facility and an increase in the rate of open defecation in Nigeria (Federal Ministry for Water Resources, 2018). The data also show that open defecation is a serious environmental problem that needs to be tackled urgently by providing affordable and accessible sanitation facilities in homes, schools and all public places (Demographic and Health Survey 2013; JMP, UNICEF 2016; WHO, 2015). Figure I shows the rate of open defection across some states of the federation.

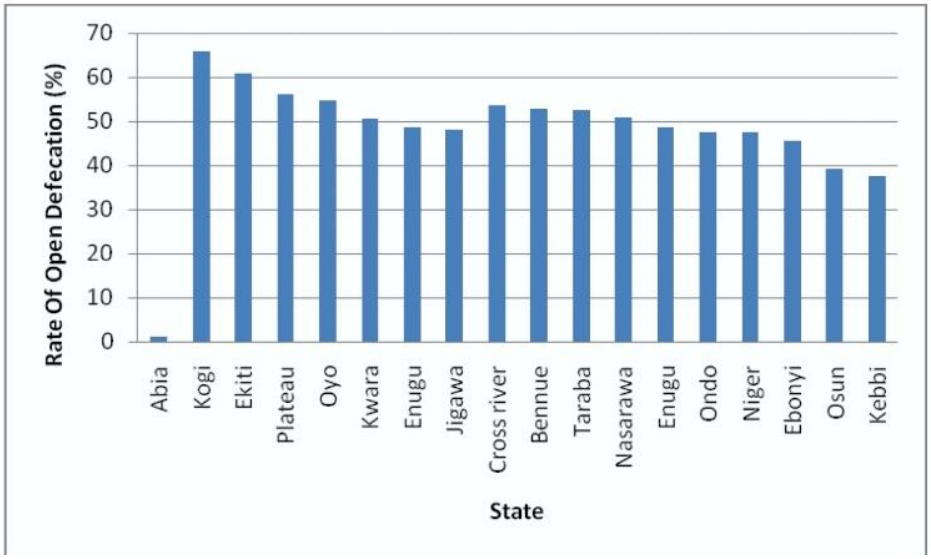

Figure I: Percentage rate of open defecation across some states in Nigeria

Impact of Open Defecation

Open defecation is a social, economic and environmental problem that is impacting significantly on the health and wellbeing of Nigeria's population particularly children and pregnant women. For example reports have indicated that, 121,800 Nigerians, including 87,000 under the age of five, die yearly from diarrhoea resulting from contaminated water, poor hygiene and sanitation (Federal Ministry for Water Resources, 2018).

Similarly, it is estimated that, Nigeria loses around ₦455 billion (US 3.6 billion dollar) a year due to activities associated with open defecation such as time spent searching for convenient places to defecate, loss of productivity due to sickness, seeking medical care, consultation and treatment and premature deaths (UNICEF, 2016). Open defecation has also exposed young girls and women to harassment, intimation and in some cases rape (Federal Ministry for Water Resources, 2018). Given the economic and health impact associated with open defecation in Nigeria, a report by JMP (2015), UNICEF (2015) and WHO (2015) recommend the provision of toilet facilities to an estimated 102,

088 million (56, 350 additional population plus 45, 7380 million currently defecating openly) Nigerians to curtail the aforementioned consequences and loses.

The provision of adequate and affordable sanitary facilities will therefore not only boost government's efforts to end open defecation by 2025 but will also aid Nigeria in meeting the United Nations revised target of open defecation free societies as well as the commitment to meet United Nations Sustainable Development Goal 6 and Partnership for Sustainable Water Supply and Sanitation Strategy.

The Quest for Toilet Efficiency and Sustainable Use of Water

Water is an essential part of human existence, which is said to be 'life' itself. Rising global population, the growing need for water couple with global climate change is however, a threat to global water supply. These bring to the fore the need to make human activity more sustainable and water efficient. One such human activity that needs to be made water efficient and sustainable is toilet flushing, which consumes between 25-35% of total indoor water use (Zaied, 2018). In view of this, studies have been carried out to reduce water wasting in toilet flushing (Zaied, 2018; An, Lee, and Kim 2014; Suratkon, Chee, and Rahman 2014; An, Lee, Jo and Kim, 2012) by advocating the installation and use of toilet systems that are water efficient such as the dual flush water closet which uses between 4.5 to 3.5 liters of water per full flush against the non-efficient ones that use 9 or more litters of water per flush.

The Impact of Cost on Accessibility of Toilet Systems

The choice of sanitary facility to install by individuals or households has been linked to economic status and level of education. For example, a study revealed that 95% of rich households with some level of education use improved highly efficient toilet facilities while only 12% of the poor use improved latrines (Federal Ministry for Water Resources, 2018).

The same study also shows that, urban dwellers with some level of education use either flush toilets with septic tank or latrine with slab while in the rural areas where level of education is generally low, pit latrine or open defecation are the most common options, while only 3% of the population without any form of education use toilet facilities, with the vast majority practicing open defecation. The study also reveal that, educated households or individuals whose income is usually high would normally install high-tech toilet facilities in their homes while those individuals who earn less will opt for the use of less efficient toilet systems or even pit latrines.

Given the rising level of poverty in Nigeria, the high cost of efficient toilet systems, which range between ₦50, 000 to ₦85, 000 depending on the brand (Table 1), couple with the fact that, majority of Nigerians live below the dollar, it is evident that, for Nigeria to successfully end open defecation, there is the need to provide affordable, efficient and sustainable alternative toilet systems for the majority of Nigerians who live below the dollar.

Table 1: Price range of different brands of toilet systems

Toilet Systems by Brand	Price range
A &C WC Seat	N50,000 - N60,000
Sweathone	N50,000 -N75,000
Nismad	N50,000 -N75,000
Virony	N65,000 - N85,000
Twyford	N45000 - N80000
Twyford squat pan	N4000 – N5000

Source: Researchers field work (2019)

Aim of the Study

The aim of the study is to develop a ceramic pour flush squat pan using local ceramic raw materials for sustainable water use and environmental hygiene.

Materials and Methods

Materials

Clay, kaolin, grog and Feldspar were used in the study for the formulation of a suitable body for the development of a ceramic squat pan. Prior to the development of the squat pan, normal procedure for raw material preparation such as grating, washing, grounding and sieving was carried out with a view to eliminating impurities such as stones, metals, glass shards that might interfere with the production process as well as providing a suitable particle size for good compaction and tensile strength. Other materials used in the study were digital weighing scale, 45 cubic foot downdraft kerosene kiln, Kerosene burner and thermocouple thermometer model 434.

Method

Design

Free hand sketches (Figure 2a & 2b) of the proposed squat pan and the mould were made for observations, alterations and modifications to ensure functionality and reliability. This was followed by full dimension drawing (Figure 3)

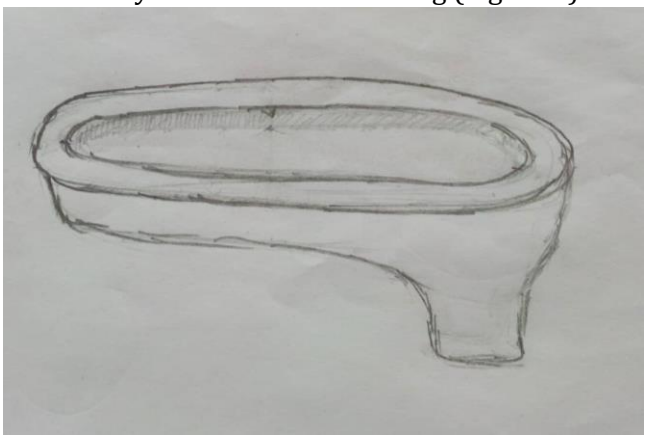

Figure 2a: freehand sketch of squat pan

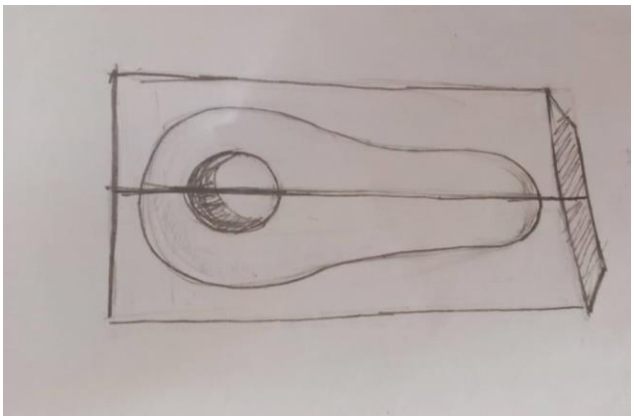

Figure 2b: freehand sketch of casting mould

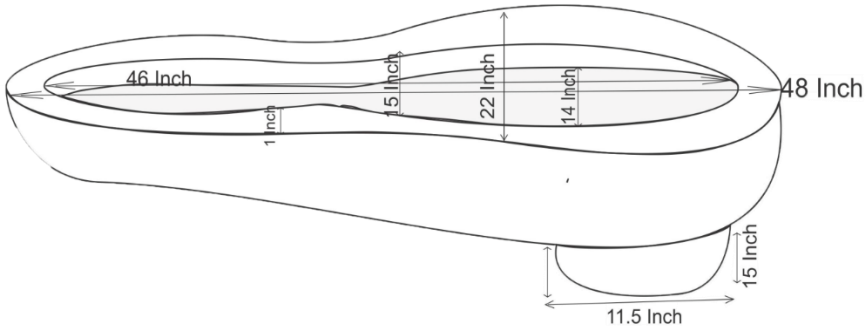

Figure 3: Dimensioned drawing of a squat pan

Batch Formulation

Quadriaxial blend of 16 tiles (Figure 4) were used to develop a body for the ceramic squat pan as recommended by Umar (2000). Quadriaxial blend of tile 3, which comprises of 32% Clay, 48% kaolin, 8% grog and 12% feldspar was selected. The choice of tile 3 was based on the outcome of a pre-test which indicated that, the body had the required plasticity and workability, mechanical strength and vitrification property for the production of sanitary ware capable of firing up to 1250^{0}C (Fortuna, Fortuna & Martini, 2017). These properties were derived from clay, kaolin, and feldspar. Kaolin improves the whiteness of the body, alumina rate and resistance to deformation at high temperature. To increase the flexural strength, green body grog was added (Hill, 1986).

Given the fact that both quartz and grog can perform the same functions, in the study, grog was used in place of quartz. The replacement was based on the availability of grog over quartz, and the fact that both grog and quartz can be used to reduce thermal expansion coefficient of the body as well reducing the firing cycle of the body resulting in reduced fuel consumption.

C- 64% K- 16% G- 16% F-4% 1	C-48% K-32% G-12% F-8% 2	C- 32% K- 48% G- 8% F- 12% 3	C- 16% K- 64% G- 4% F-16% 4
C- 48% K- 12% G- 32% F- 8% 5	C- 36% K- 24% G- 24% F- 16% 6	C- 24% K- 36% G- 16% F- 24% 7	C- 12% K- 48% G- 8% F- 32% 8
C- 32% K- 8% G- 48% F-12% 9	C- 24% K- 16% G- 36% F- 14% 10	C- 16% K- 24% G- 24% F-36% 11	C- 8% K- 32% G- 12% F-48% 12
C-16% K- 4% G- 64% F-16% 13	C- 12% K- 8% G- 48% F-32% 14	C- 8% K- 12% G- 32% F-48% 15	C- 4% K- 16% G- 16% F- 64% 16

Figure 4: Quadriaxial of blend of 16 tiles

The squat pan was then formed from a blend of materials on tile 3 using slip casting technique and a mould developed from plaster of Paris (Plate 1a & b).

Plate 1a: Front view of a plaster mould

Plate 1b: Rear view of a plaster mould

Shrinkage, Water Absorption and Flexural Strength

To comply with international safety and hygienic requirements, parameters such as shrinkage, water absorption rate and flexural strength were determined based on ASTM standards C-373-72 and C-326-76.

Glaze composition

To enhance the aesthetic quality of ceramic pour flush squat pan and make it impervious, a glaze composition of 50% feldspar, 30% kaolin, 15% ball clay and 5% zircon was made and applied to the squat pan and fired to a gloss temperature. The aforementioned glaze recipe was chosen to ensure compatibility between body and glaze with a view to eliminating crazing and peeling.

Firing

The developed squat pan was fired to bisque and gloss temperature in a reducing kiln atmosphere (Plate 2a & b)

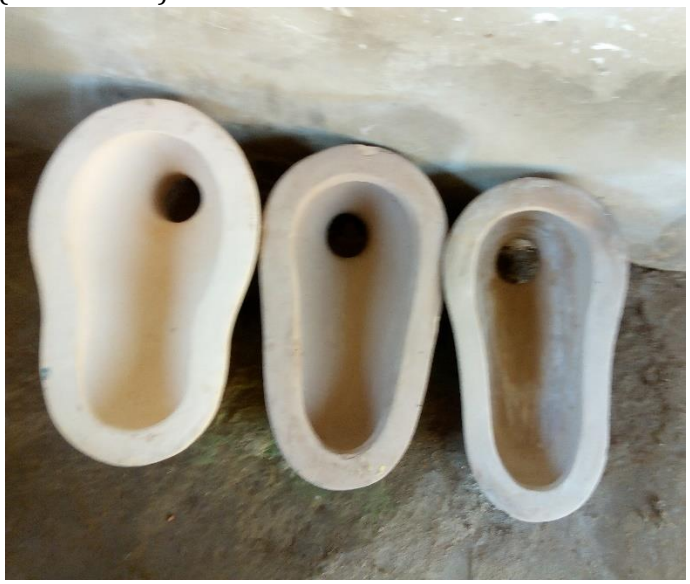

Plate 2b: Bisque fired Squat Pan

Plate 2b: Gloss fired Squat pan

Results and Discussions

Flexural Strength, Water absorption and Shrinkage Rate of the Squat Pan Body

The result of the flexural strength indicated that, the body has the capacity to withstand a pressure of 40.50 Mega Pascal (MPa). Similarly the results of shrinkage level and water absorption revealed that, the body has 10.95% and 0.4% shrinkage and water absorption rates respectively. These values are comparable to the international standards that require a flexural strength of above 40 MPa. If the ware is to withstand the rigor of handling and use without brakeage, water absorption rate of less than 0.5% and a shrinkage rate of less than 12% (Martini, Fortuna, Fortuna, Rubino & Tagliaferri, 2017) are to be ensured.

Firing

The developed Ceramic Pour Flush Squat Pan was first fired to a bisque temperature of 900^{o}C in 5 hours (Figure 5) and then to a medium stoneware temperature of 1220^{o}C in reducing atmosphere for 7 and the half hours (Figure 6)

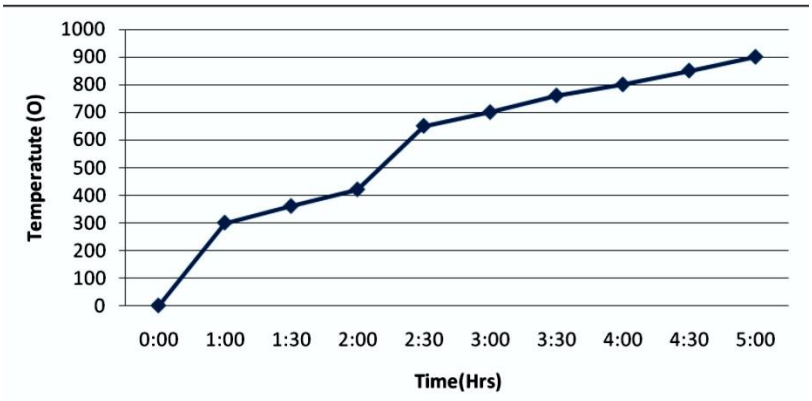

Figure 5: Bisque firing temperature and time relationship

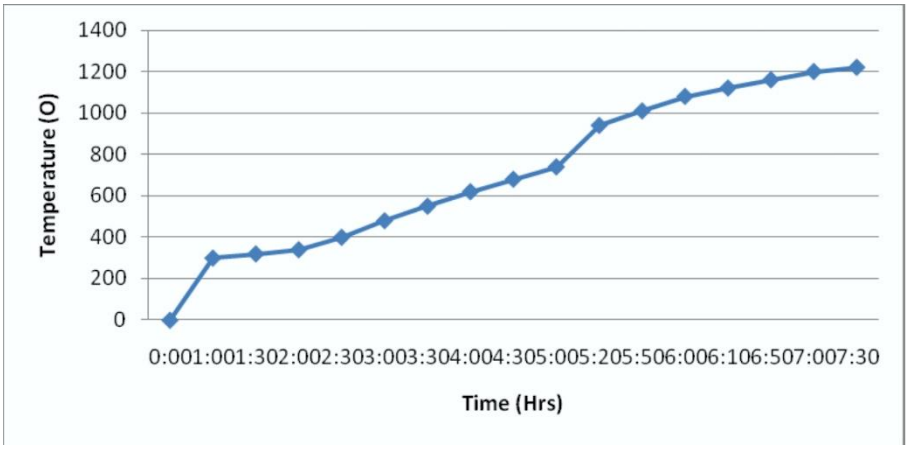

Figure 6: Gloss firig temperature and time relationship

The result of the firing also indicated that, the replacement of quartz with grog did not appear to affect the physical and mechanical properties of the squat pan. Based on the material composition of the squat pan, however, it was expected that, the body vitrified at 1250^{o}C instead of the recorded 1220^{o}C. The reduction in firing temperature was attributed to reduction in the silica content of the body resulting from the replacement of quartz with grog. This is consistent with Martini, et al. (2017) who also report a decrease in firing temperature when quart and feldspar were replaced with recycle glass.

Functionality and Water Efficiency Test

The squat pan produced from a blend of ball clay, kaolin, feldspar and grog was tested for functionality and water efficiency and the result indicated that the recorded flexural strength, water absorption and shrinkage rate made the pan hygienic, with a capacity to withstand pressure from usage. In terms of water efficiency, the test showed that, only 1 litre of water was required to flush the developed pan (Plate 3) against the 4.5 to 3.5 litres of water required to flush a dual flush toilet system (Plate 4), the two litres required to flush an imported squat pan (Plate5), or 1 bucket of water required to flush dual pit off-site flush flow latrine. The result also revealed that, the cost price of ₦2, 500 for the developed squat pan made it cheaper than the ₦4000 to ₦5000 cost price of imported squat pan.

Plate 3: Developed squat pan

Plate 4: Dual flush toilet system

Plate 5: Imported squat pan

Conclusion

A blend of clay (32%), kaolin (48%), grog (8%) and feldspar (12%) was found to be suitable for the production of ceramic squat pan. Similarly, the flexural strength of 40.50%, water absorption rate of 10.5% and shrinkage level of 0.4% recorded were enough to provide the standard hygienic quality and strength required for sanitary ware to withstand the rigor of handling and use. The developed pour flush ceramic squat pan is cost effective and more water efficient than the dual flush system which require up to 4.5 litres of water per flush. The adoption of the squat in both rural and urban areas will boost the effort of the federal government of Nigeria in ending open defecation by 2025.

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