Original Research Article

Characterization of clay from Isan Ekiti Deposits for making the Ceramic Water Purifier

ABSTRACT

Introduction: Despite the efforts of Governments and non-governmental organizations in sponsoring ceramic water purifier (CWP) filter project across the globe, some rural communities in Ekiti State, Nigeria are yet to benefit from it. One of the major technical difficulties hindering the making of CWP filter cells in many places was the adaptation to the sand, clay and sawdust mixture necessary to obtain the correct filter properties.

Aim: In this study, some salient properties of clay from *orudi*, *arade* and *oturo* deposits at Isan Ekiti were assessed in the light of their usefulness for making the ceramic water filter cells.

Methodology: The particle size distribution analysis and consistency tests were carried out on the crude clay. Also the shrinkage, effects of percentage constituents of burnout on porosity, filtration rate and quality of filtrate were measured, using standard methods.

Results: Results show that *arade* has the appropriate technical properties for making the filter cell. The chosen clay sample has its deposit less than 2 kilometers to the point of making. About 56% of its particles are less than 0.075mm equivalent spherical diameter (ESD). A composition of ratio 50:50 by volume mixture of clay to sawdust has the porosity of 54. 55% while that of ratio 40:60 is 55.56%. Samples made of these batches were capable of reducing the water turbidity Neflometric Turbidity Unit (NTU) of contaminated water by 95%. The 50:50 samples have the higher capacity of reducing total coliform count by 50.28% as against 25.07% for 40:60 samples.

Conclusion: Given appropriate facilities and training, with the abundant clay at *arade* deposit, the pottery center is a place where CWP filter cell factory could be established.

Keywords: Isan Clay, porosity, Water purifier, Filter cell, Flow rate, Turbidity, Coliform count

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1. INTRODUCTION

Since 2020, over 60 million people, mostly in the rural communities in Nigeria, lack access to safe drinking water. The Vision 20:2020 and Millennium Development Goals (MDGs) are a few of national and international initiatives that address improved sanitation and access to safe water. In this direction, government and non-governmental organizations sponsors ceramic water purifier (CWP) filter project across the globe [1], but Ekiti state of Nigeria is yet to enjoy the program. Despite the abundant clay and ready source of burnout such as saw dust, there is yet to be a factory for the production of CWP cell in Ekiti state. Consequently, many local communities in the state still suffer lack of access to portable water. For instance, an assessment of the water quantity, quality, and access to water source in Otunja Community of Ikole –Ekiti Local Government Area, showed that 17 out of the 40 households surveyed did not have access to domestic water that meet the Nigerian Standard for Drinking Water Quality [2]. Studies at Ekiti South (Ikere and Omuo), Ekiti Central (Ado and Ijero) and Ekiti North (Ido and Ikole) Senatorial Districts revealed that people living in these areas of the state have no access to potable water. Even Ado Local Government Area which is the state capital had just 8% of her population with access to potable water [3]. The unavailability of safe water makes residents resort to hand dug wells, streams, rivers and other unsafe sources [4]. It was observed that the health status of a community is a function of access to potable water, and that those who drink from unprotected or untreated water, are prone to water borne diseaseas as it is common in some settlements in Nigeria. They may suffer water-related ailments which include cholera, typhoid -fever, giardiasis, dysentery, salmonella among others. In recent years, water pollution has turned out to be a severe problem in most countries of the world especially the developing countries, which primarily occurs due to the indiscriminate disposal of untreated effluents and other chemical and agricultural waste [19]. Thermal treatment of kaolin clays gives rise to formation of amorphous material which can produce reactive silicate and aluminate species. These species are capable of reacting with calcium hydroxide solution that forms during cement hydration to generate stable insoluble compounds (calcium-silicate-hydrate and calcium-aluminate-hydrate) which possesses cementitious properties [20].

Bankole [5], studied the geographical distribution of water supply in Ekiti State, and observed that there are problems militating against the supply of clean water to some people living in the state. A number of solutions were then proposed, which include the rehabilitation of existing dams, provision of funds, completion of the 132 KVA, involvement of communities in monitoring and further collaboration of the state government with the existing donor agencies. These suggested solutions would not only be money and time consuming but also would require experts and special skills. Meanwhile, the CWP, which is cheaper and a user-friendly solution, approved by WHO as a drinking water treatment systems, suitable for the tropical conditions in developing countries such as Nigeria [1], was not considered in the suggestions. This study therefore seeks to investigate the merit indices of the available clay at some popular deposits in Isan Ekiti, with the view of possible establishment of CWP filter factory in the state.

One of the communities of Isan Ekiti that may be exposed to the risk of contaminated water has potential capability of CWP filter production. This community rely on water sources like hand dug well such as Ajetunmobi Compound, Isan, Adetifa Compound, Isan, a bore hole called solar at Isan, the well near palace at Itaji, and Olorunda stream at Ilemeso (Figure 1). Whereas, its environment is blessed with abundant pottery clay that could be used for making CWP filer cells if properly manipulated.

Figure 1: Omi Olounda, a major source of drinking water for the people of Ilemosho

It is a known fact that the characteristics of clays differ from place to place, in accordance with the geologic origin. The plasticity and sand content would determine the amount of other constituents that could be added to make it moldable. These constituents would also determine the drying shrinkage which will in turn dictate the dimensions of the mold for production and how safe is working with the clay without the risk of drying and firing problems. The type and quantity of additive constituents will determine the finished properties such as porosity and rate of flow of the filter cells. Since the usefulness of a clay depends on its characteristics, it is therefore important to characterize the clay at Isan deposits in order to make a choice for the formulation of a workable batch for making filter cell from any of the clay samples.

Lantagne [6] observed that a major technical difficulties encountered during the establishment of filter cell factory in many places was adaptation to the sand, clay and sawdust mixture necessary to obtain the correct porosity. Different centers reported different percentage mixtures. For instance, at Nicaragua, a ratio of 50:50 sawdust to clay was quoted as the batch composition, whereas, 60 to 40 (clay: sawdust) was quoted for Cambodia project. It is pertinent for this study then, to focus on the formulation of standard batch from the clay materials used by the potters to provide background information that would ease the task of establishing a filter factory at Isan Ekiti.

2. MATERIAL AND METHODS

2.1 Study area

Isan Ekiti is a pottery community in Oye Local Government of Ekiti State Nigeria (Figure 2). The area lies within latitude 7^o 52' N and longitude 5^o 19' E. The community is blessed with abundant clay, which made the people especially women to take to pottery [7]. They make pots for holding water, but never made pot for filtering water. The pots from the center are porous terracotta body and this suggests the possibility of adapting the clay for the production of CWP filter cell.

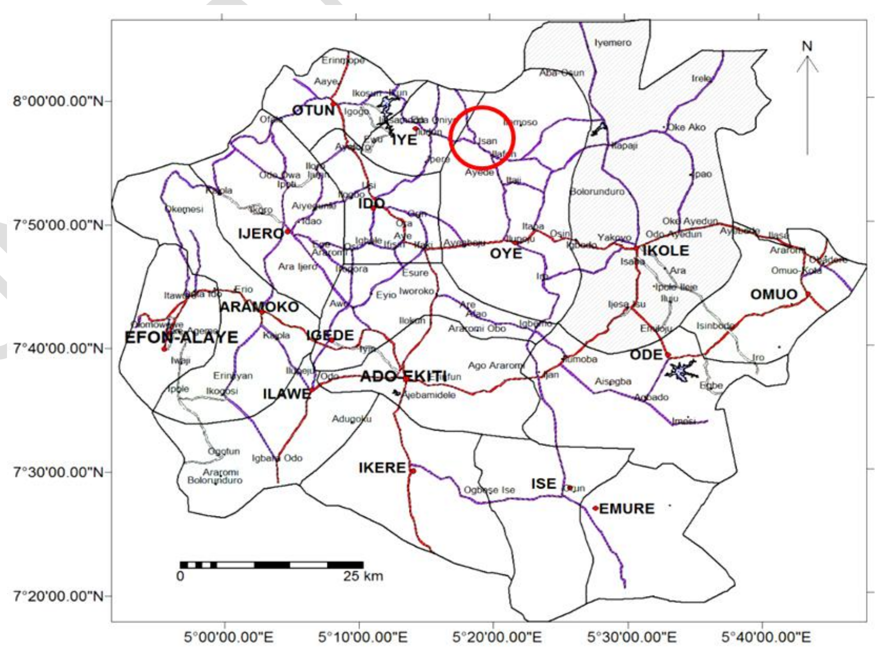

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Figure 2: Map of Ekiti state showing the study area encircled

2.2 Sample collection

Clay samples were collected from *orudi*, *arade* and *oturo* deposits for examination as these locations have major clay deposits. The samples were dried in an electric furnace at 110°C for 12 hours, then materials were pulverized and sieved through a 590-micron sieve manually. The powders were appropriately conditioned for the specific tests. The parameters measured were: particle size analysis, plasticity, for crude samples while shrinkage, scratch hardness, porosity, and efficiency of the fired sample batches to reduce turbidity and microbial load of water filtered through them.

2.3 Particle size analysis

The test was performed to determine the different grain sizes contained within the clay. The distribution of the particle sizes affects the packing density of the pressed piece and would in turn determine its porosity and permeability which is a factor for the intended finished product. The wet sieve method as described by ASTM C92 (standard method for particle size analysis) was used for particle sizes above 75 microns and the hydrometer method as described by ASTM D 422 – Standard Test Method for Particle-Size Analysis of Soils - was used for sizes below 75 microns.

2.4 Body composition

The batch composition is presented in Table 1. The clays, *orudi*, *arade* and *oturo* were denoted as samples A, B and C respectively. The sawdust and clay were dried in an electric dryer at 105^{o} C for 8 hours, before screening. The three sourced clays and the sawdust were screen through a 30 mesh (590-micron aperture) sieve separately, using hand sieving method. Samples were taken by conning and quartering method. In order to control the porosity in each sample batch, the amount of sawdust added in the mixing stage was varied across a range of volume percentage.

Table 1: Batch composition with different clay/sawdust proportions

Materials	**Sample batch**							
	I	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**
%Clay	10	20	30	40	50	60	70	80
% Saw Dust	90	80	70	60	50	40	30	20

2.5 Determination of bonding power

The bonding power of a clay is considered to be its ability to impart strength to a dried mixture made up in part of materials less plastic than itself. It is somewhat an indirect means of measuring the plasticity of the clay. This is important in a case such as the mixture of clay and sawdust. The parameter was determined by measuring the effect of adding varying quantities of sawdust to clay/water system as described by Rosa [8]. To a plastic clay of known dry volume,containing 50% moisture content, sawdust was added progressively, in varying ratio of the clay dry volume as shown on table 1, and kneading the mixture each time sawdust is added until the mass is no longer coherent. The plasticity was adjudged by the ability to deform without craking. The limit of sawdust addition was taken by the coherency of the mix at certain percentage sawdust content when rolled into a ball. Subsequently, workable batches were selected.

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2.6 Praparation of Test Pieces

Sample test pieces were prepared in the form of disk tablets from workable compositions. They were formed by pressing into discs of diameter 65 mm and 15 mm in thickness. In order to achieve approximately uniform sizes, a container was used to measure the rough size before pressing. The pressed pieces were left to dry naturally for two days under room temperature. It was later transferred to the electric dryer where it was forced dried. When they had been thoroughly dried, they were fired in a gas fueled kiln to the temperature of 880^{o}C. This temperature was chosen because the local porters fire pots made from these clays, of average wall thickness of 5 – 6 mm to the temperature of 780 ^{o}C. while the samples are of thicker wall (15mm). This temperature would make the final ware stronger without getting overfired.

2.7 Total Shrinkage test

The total shrinkage was taken in order to estimate the mold size for shaping the raw piece which will eventually shrink to the size that would fit the preselected plastic receptacle. The method explained by Ryan [9] was used. The linear shrinkage was taken by measuring the diameters of representative disks immediately after shaping (wet length- L_w) and after firing (fired length -L_f). Shrinkage percent was then calculated using the relation

$$\%C = \frac{L_w - L_f}{L_w} \times \frac{100}{1}$$

Five test pieces were prepared from each of the 11 batch compositions. The test was replicated and the average values were calculated. The value of the shrinkage is not expected to be more than 10 – 15% in order to avert drying and firing faults such as warping and cracking.

2.8 Scratch hardness test

The hardness test was carried out using the scratching method based on the reference stones of the Mohr's scale of hardness. This is rough measure of the resistance of a surface to scratching or abrasion. The fingernail, the copper coin and a piece of window glass which are approximately of scale 2.2, 3.2 and 5.5 respectively in the Moh's scale of hardness were used as the scratching medium.

2.9 Porosity test

Porosity is defined as the proportion of air space or voids between solid particles of a given material. The voids are of different types such as sealed pores, which is not accessible to liquid, channels and pocket in which liquid penetrate and stored in the pocket; microspores that is too small to admit liquid and interconnected pores that are of importance to the filter cell. The porosity was measured in accordance with the ASTM standard. Five test pieces were tested from each sample and their averages obtained. The following formulae were used to obtain porosity values:

Volume of open pores and impervious portion, V cm^3 = W – D

Volume of impervious portions, cm^3 = D – S.

Apparent porosity, P % = [(W – D) / V] × 100

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Where D is dry weight, S is suspended weight, W is saturated weight in air

2.10 Filtration rate

A disc made from each sample piece was affixed unto a cylinder of five centimeters in diameter; the cylinder was then filled with 500cl of water and timed. The quantity of water filtered at the expiration of four hours was measured. Sample pieces each was fixed to the one end of a plastic pipe of 35cm long and 5 cm in diameter with silicone adhesive. The test was carried out on five pieces from each sample and three runs for each test piece. The quantity of filtrate was then measured.

Figure 3: Experimental set up for filtration rate test

2.11 Turbidity of filtrates

Turbidity refers to cloudiness caused by very small particles of silt, clay and other substances suspended in water. A slight degree of turbidity in drinking water is objectionable to most people. Turbidity also interferes with disinfectant by creating a possible shield for pathogenic organisms. Samples of turbid water were drawn from Ureje stream along Federal Polytechnic Road Ado-Ekiti (U) and water from Aba-corner (K) along Ikare Ado Road. The light scattering instrument was used to assess the raw and filtered samples of water. It was calibrated with 200 Nephelometric Turbidity Units (N T U) standard solution for the upper limit and to zero with distilled water for the lower limit. The sample bottle was then filled in turn with the samples and the turbidities taken. Three trials were made for each sample and the mean reading was calculated.

2.12 Determination of the efficiency to reduce microbial load of water

Microbiological analysis was carried out on both raw and treated samples of water obtained from Ureje stream and a well at **Aba Corner** along Ikare road. The pour plate method was used in the analysis. Serial dilution of each sample was prepared up to 10^{-3}. The following

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media were prepared according to the manufactures specification, potatoes dextrose agar (PDA), violent red bile agar containing neutral red pH indicator, mannitol salt agar and plate count agar. 1ml of each of the water sample was transferred into different plates using sterile pipettes and approximately 20ml of each medium was poured into the different plates and swirled gently. When the media in the plates have solidified, all expect PDA, (which was incubated at room temperature for 5 days) were incubated at 37^{o}C for 24 hours. Violent red bile agar plates were observed for coliform growth, the mannitol salt agar plates were observed for the growth of staphylococcus aureus and plate count agar plates were observed for total bacteria count. After five days, the PDA was observed for fungi growth. The efficiency at reducing microbial load (E%) was calculated thus;

$$E(\%) = \frac{L_i - L_f}{L_i} \times 100$$

Where L_i is the initial microbial load of water and L_f is the final microbial load after filtration.

3. RESULTS AND DISCUSSION

The following are the results obtained from the investigation.

3.1 Particle size analysis

The wet sieve analysis shows that all the particles of *oturo* samples passed through sieve of 0.075mm aperture. The hydrometer method was then used to determine its particle size distribution as shown on figure 4. The particles are almost uniform clustering between 0.005 and 0.02mm. Figure 5 shows the result of the sieve analysis of *orudi* and *arade* samples. *Orudi* has more than 50% of its particle size greater than 0.6 mm. This portion of the clay falls into the category of sand (which is non-plastic) according to Globe [10]. That is, the particle size of course sand ranges from 2 – 4.75mm, Medium sand ranges from 0.425 – 2 mm and fine sand ranges from 0.075 – 0.425 mm. This is may be why the sample was not moldable at clay sawdust ratio 20:80. *Arade* has well graded particle size distribution and this might be why it demonstrated better parking density in accordance with Mamlouk and Zaniewski [11]. Lantagne [6] reported that ‘in the PFP example of sorting grain size between two screens (#30 & #60). This means that uniform (poorly graded) grain size between 0.84 mm and 0.25 mm would be ideal particle size for filter production. In this wise oturo may be thought to be out of useful range, while only about 34.5% of orudi and 28% of arade may be useful for making the filter cell respectively.

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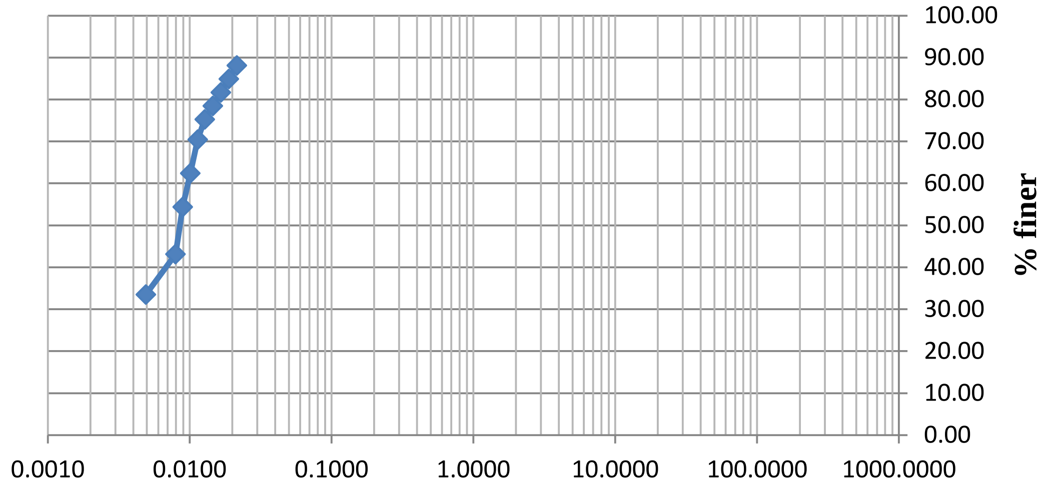


Figure 4: Particle size distribution of *oturo* sample

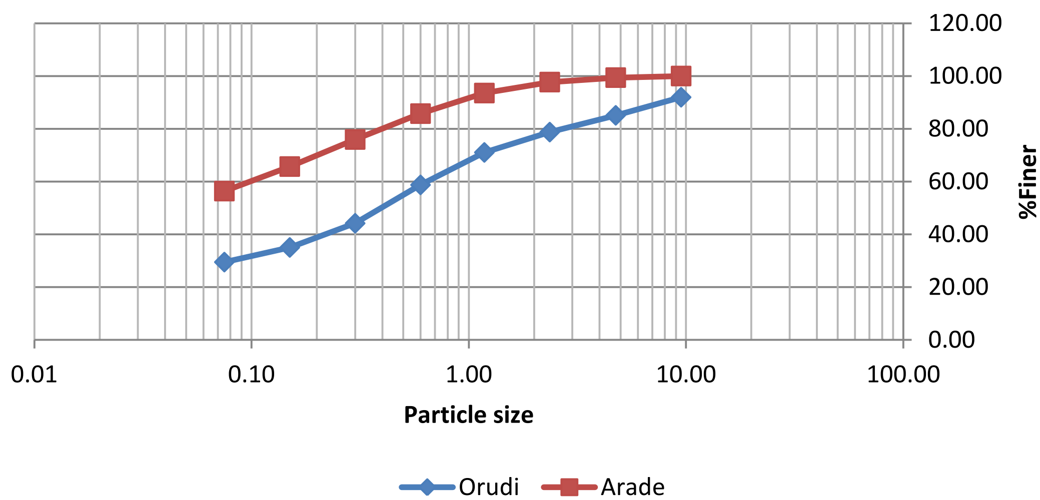


Figure 5: Particle size distribution of Arade and Orudi samples

3.2 Bonding Power

Orudi clay loses coherency at 40 % clay content and only becomes mouldable without cracks as from 50:50 mix ratio. Both *Oturo* and *Arade* are mouldable as from 40:60 mix ratio. This goes to say that *Orudi* is less plastic compared to *Oturo* or *Arade* and that the plasticity of the clay determines the limit to which sawdust can be added to the mix. Ratios above 80 were not considered since no filtrate had been reported [11].

3.3 Total shrinkage of samples

This parameter was measured for clay-sawdust mix. Shrinkages of the mixes vary from clay to clay (Figure 6). This may be due to the amount of fine particle material present in the respective constituent clay. The clay samples show different shrinkages in responses to sawdust addition. *Oturo* samples show the highest shrinkage at ratio 50:50; *arade* shows the highest shrinkage at ratio 80:20, while *orudi* shows the highest shrinkage at ratio 60:40. From the foregoing, the type of clay used would dictate the size of mold. As shown on table 2, there is positive correlation between shrinkage and clay content but not perfect. The imperfection may be as a result of the influence of the sawdust addition and the clay texture. The trend of increase in shrinkage with increase in clay content is in agreement with the findings of El-Halim and El-Baroundy [12] that linear shrinkage decreases with increasing sawdust. Decreasing saw dust means increasing clay and consequently increasing shrinkage. Higher shrinkage values shown by oturo samples confirm that clays with finer particle sizes have greater shrinkage, which increases as does plasticity. Also, the amount of shrinkage depends apart from particle size on many other factors like the distribution of sizes, the shapes and the proportion of other types of particles present (such as saw dust) [13].

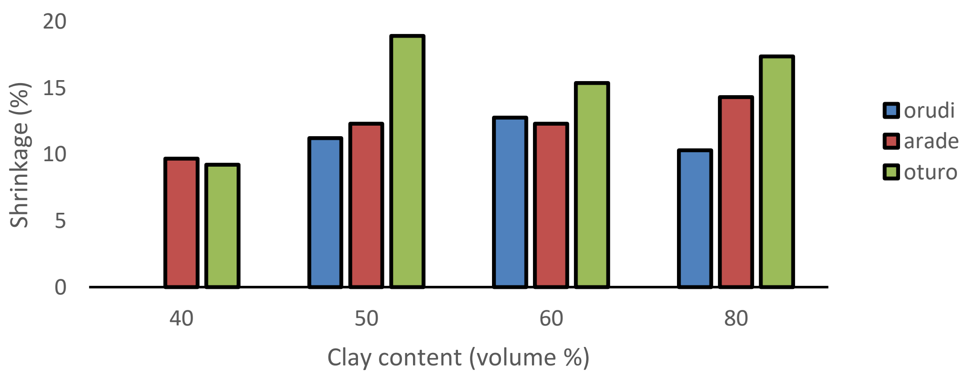


Figure 6: Total shrinkage of samples

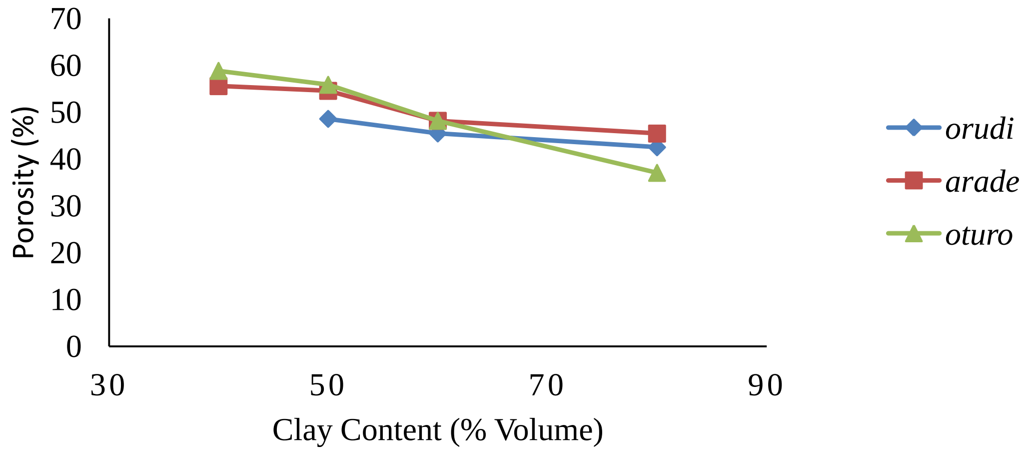
Table 2: Relationship between clay content and shrinkage

Correlations

		Shrinkage	Content
Shrinkage	Pearson Correlation	1	.354
	Sig. (2-tailed)		.285
	N	11	11
Clay Content	Pearson Correlation	.354	1
	Sig. (2-tailed)	.285	
	N	11	11

3.4 Porosity

Figure 7 shows the degree of porosity of each sample batches. For all the sample clay, porosity decreases with increase in clay content. Changes in porosity with increase in clay content manifest most in Oturo sample. This might be as a result of almost uniform particle size distribution and perhaps higher loss on ignition (presence of organic matter in the raw



clay). For all the clay type, the correlation between clay content and porosity is significant. As shown on table 3, the correlation is negative as the higher the clay content in the mix the lower the porosity. This is in agreement with the observation of Majid et al [14], porosity of the filter increased linearly with an increase in the amount of sawdust.

Figure 7: Effect of clay content on Porosity

Table 3: Relationship between clay content and porosity

Correlations

		porosity	claycont
Porosity	Pearson Correlation	1	-.894**
	Sig. (2-tailed)		.000
	N	11	11
Clay content	Pearson Correlation	-.894**	1
	Sig. (2-tailed)	.000	
	N	11	11

**. Correlation is significant at the 0.01 level (2-tailed).

3.5 Scratch hardness test

The result of scratch hardness of all mixtures made of *Orudi* clay were less than scale 3 of the Moh scale of hardness. Even the finger nail can scratch them.. Orudi has higher porosity and hence lower value of scratch hardness. This is agreement with the description of PSAP [15] that porous ceramics are easily scratched and permeable to liquids. Oturo and arade have hardness scale of about 3. This value is in resonance with the value assigned to ceramic mass after bisque firing according to the current Mohs scale of hardness by Holst Porzellan/Germany [16]. Hence they may be resistant to abrasion by sponge when washed.

3.6 Rate of filtration

The filtration rate was measured on the basis of liters per meter per hour (l/m^2hr^{-1}). This is to bring about unified measure of the rate based on the surface area of a filter cell irrespective of size or shape. On figure 8, *orudi* at 50% clay content, shows the highest filtration rate followed by *arade* and oturo respectively. These rates follow the same trend as the porosity values. Trend agrees with the findings of Nnaji et al. [17] that the flow rate vary with increase in proportion of sawdust. However, rates of decrease in porosity as clay contents increase vary from clay to clay and this also may depend on the texture of the particular clay. For instance, at 60% clay content it appears that the higher the fine particle content, the lower the porosity and consequently the lower the filtration rate. Orudi would have been the best but for the coloration of the filtrate due to particles that wears from the sample. Arade B4 and B5 became the choices for further assessment.

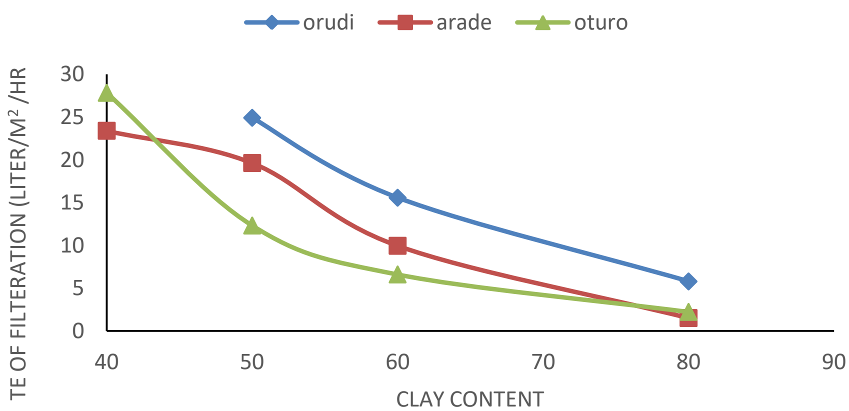


Figure 8: Effect of % Content of Samples Clay on rate of filtration

3.7 Turbidity of filtrates

As shown on table 4, both samples were able to reduce the turbidity to 2.0 NTU irrespective of the degree of turbidity of the raw water. This value is below 5NTU, which is the maximum allowed by World Health Organization (WHO) for drinking water. The pore size and pore size distribution of a filter are important in determining the filters' efficacy at removing particulates from water. Since the values of filtrate turbidity, for varying degrees of initial turbidity of raw water, are the same, it appears that the efficiency at reducing turbidity is dependent on the size of the suspension in the water and the pore size of the filter.

Table 4: Efficiency of selected sample to remove turbidity

Water source	Turbidity Values		
	Raw	B4 Filtrates	B5 Filtrate
Ureje	40	2.2	2.0
Aba corner	17	2.0	2.0

3.8 Efficiency in Reducing Microbial Load

The reasons for reduction in microbial load is that the WHO recommends zero per 100ml. it considers 1-10 as low risk 10-100 intermediate risk,100-100 high risk and >1000 to very high risk [18]. Figure 9 shows that the efficiency at reducing microorganisms increases with increase in clay content of mix. The value obtained for sample B5 (arade with 50% clay) maintains higher values of efficiency for all the microbes. Though these values are lower than the ones obtained by Bulta & Micheal [1], however, the impregnation of the filter pots with colloidal silver may greatly improve the efficiency at removing microbial contamination. Without impregnation with colloidal silver, these sample would only be useful o treat water of intermediate risk by reducing it to low risk status.

Increasing sawdust content beyond the proportions used in this research will impair the quality of filtrate as well as the structural integrity of the filters. The rate of water discharge by CWF increases with porosity, or in other words with the fraction of sawdust used in making the filter using pyknometry techniques

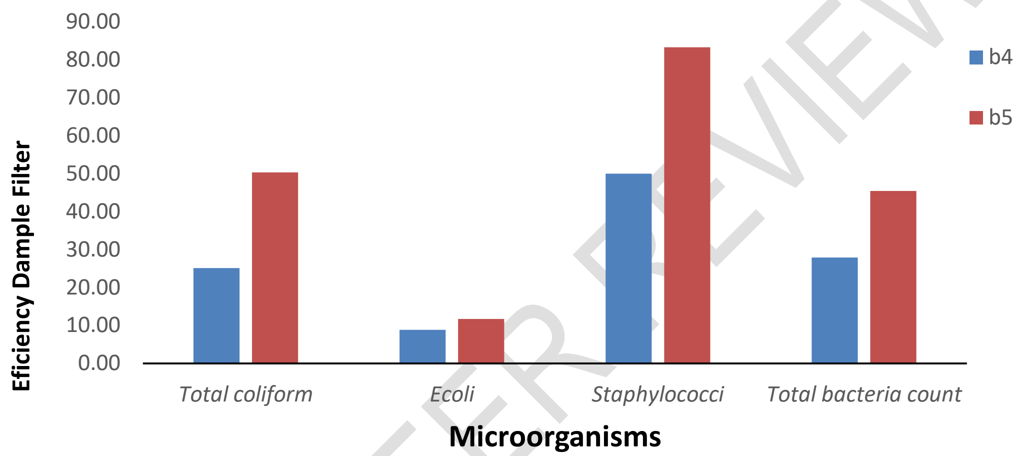


Figure 9: Efficiency of selected samples to reduce microbial load

4. CONCLUSION

The clay with higher coarse particles sizes tends to be of higher filtration rate even with lower amount of burnout due to lower plasticity, which also makes it to be of low mechanical strength, and poor efficiency in removal of coliforms. The clay with higher fine particle size and of almost uniform particle size tends to be of higher filtration rate due to its higher plasticity which made higher burnout content possible. It is equally of higher mechanical strength which makes it more resistant to abrasion. The well graded clay sample tends to be of average values in rate of filtration, appreciable scratch hardness and though poor but of higher efficiency to remove coliform than the clay with coarser particle sizes. The sample clay which was rejected on the ground of excessive shrinkage is recommended for further investigation for improvement. It could be concluded that the clay with high fine particles may still be moldable with higher addition of sawdust beyond 40% by weight. The higher saw dust ratio may increase the filtration rate and the small particles may make the pore size so small that it may be of higher efficiency to remove microbes from contaminated water.

DISCLAIMER

Authors have declared that no competing interests exist. The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because

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we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

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