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Evaluation of the mixtures of clay, diatomite, and sawdust for production of ceramic pot filters for water treatment interventions using locally sourced materials

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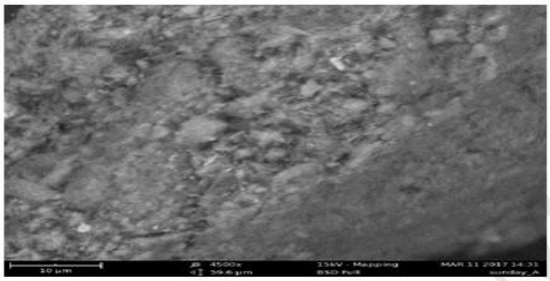
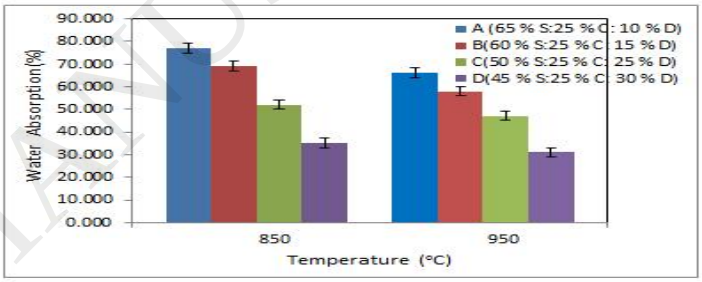
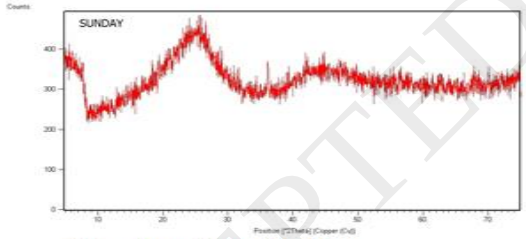
Graphical abstract



SEM of formulated clay



Water absorption at different temperatures



XRD pattern of formulated clay

CPF Sample A

Source of drinking water for rural Community (Neke)

Abstract

The need to improve the flow rate and maintain the quality of filtrate using ceramic pot filter (CPF) so as to improve the access to potable water in rural areas informed this work. Mixtures of clay, diatomite and sawdust were utilized in the production of CPFs. The percentage mixtures were; A (sawdust 65, clay 25, diatomite 10) B (sawdust 60, clay 25, diatomite 15), C (sawdust 50, clay 25, diatomite 25) and D (sawdust 45, clay 25, diatomite 30). Physical analyses of the clay were done after firing at 850^{o}C and 950^{o}C. Chemical characterization of the clay sample with the compounded mixtures was done using X-ray fluorescence spectrophotometer and X-ray diffractometer. The solid casting method was employed in the production of CPFs and fired at

850°C and 950°C. The flow rates of CPFs were determined, with Sample A, giving the highest flow rate of 2.5L/h followed by B (2.0L/h), C (0.2L/h) and D (0.06L/h). Results showed that sample A has the best physical properties determined, with the best firing temperature of 850°C. The choice Sample A was further tested and compared with B, by usage in treating water samples from a rural community. The morphology of the selected sample was determined using a Scanning Electron Microscope. Analyses of the untreated and treated water samples showed removal efficiencies for turbidity, TDS, TSS, E coli and coliform as 79%, 64%, 62%, 100% and 100% respectively. All results obtained were within the WHO limit. Results confirmed the suitability of the materials for CPFs production.

Keywords: Ceramic, pot, filter, water, clay

1 Introduction

The need for improvements in safe drinking water coverage worldwide has recently been receiving more attention as one of the global health topics of highest priority. Seventeen Sustainable Development Goals was set by the United Nations; target ten to half the proportion of the people without sustainable access to safe drinking water and basic sanitation by 2015. The deadline has come and gone about six hundred people are still without access to safe water (WHO/UNICEF, 2000). Access to safe water and sanitation coverage rates in Nigeria are amongst the lowest in the world (WHO/UNICEF, 2000). Drinking water is the main source of exposure to pathogens and chemical contaminants (Hrudey and Rizak, 2004). Waterborne pathogens such as bacteria, viruses, and protozoa pose a greater threat than chemical contaminants because of the immediate and severe health effects while the adverse effects of chemical pollutants occur after a very prolonged period of exposure (Rayner, 2009; Radin, 2018).

Despite major efforts to deliver safe piped community water, some rural communities have not benefited from it. Isi-Uzo is an agrarian local government area situated in the undulating lowlands of North East flank of Enugu State. The major sources of water in the five major communities of Mbu, Neke, Umualor, Ikem and Eha-Amufu that make up the local government are Amanyi and Ebenyi streams. There has never been any borehole in the entire five communities that anyone can remember. The only source of drinking or other domestic water is through the flowing streams and the water is usually highly turbid during the rainy seasons.

The methods of purification like chlorination, large-scale filtration cannot be afforded by many Nigerians especially rural people who live below poverty levels. Ceramic water filter has become

a cheap and efficient method for purifying water in rural areas since all the materials required are available locally and has a relatively long lifetime of 2-3 years (Brown, 2007, Saja *et al.*, 2017; Bocanegra *et al.*, 2017). Filtration is one of the most effective yet simplest water treatment processes (Sobsey, 2008). Previous works have been done to test the effectiveness of ceramic filter in treating water (Abiriga and Kinyera, 2014; Agbo *et al.*, 2015; Ali *et al., 2017;* Ajayi and Lamidi, 2015; van Halem, 2009; Islam, 2014; Jalali *et al.*, 2016; Kabagambe, 2007 and Erhuanga, 2014; Mohamed *et al*., 2016; Nair and Kani, 2017*;* Olalekan *et al.*, 2015).

There have been a number of studies done on the physical and chemical properties of clay from Ukpor. Edoziuno *et al.*, (2015) studied the effect of Ukpor clay content on the properties of synthetic moulding sand produced from River Niger sand. Akpomie *et al.*, (2012) characterized some clay samples and determined the mechanical strength of the sintered samples; they modelled the porosity dependence of the adsorptive abilities of the kaolin, the structure and composition of kaolin which is found in many parts of Nigeria as small platelet particles of aluminum silica. From these studies, results show that clay from Ukpor has physical and chemical properties suited for use as electrical insulators and heavy metal removal. The porosity studies have not been considered in relation to the possible use of the samples as ceramic water filters.

From literature and to the best of our knowledge clay from Ukpor has not been considered in relation to possible use as ceramic water filters, hence this study is geared towards evaluating the mixtures of clay, diatomite, and sawdust in the production of ceramic water filter pots for household water treatments in rural communities. This work also seeks to improve on the flow rate and maintain the quality of the filtrate using CPF so as to improve the access to potable water in the rural areas.

2 Materials and methods

2.1 Materials

The clay samples used in this study was collected from Ukpor, Nnewi South Local Government in Anambra State, diatomite from Jos in Plateau state and sawdust from New market timber shop at Enugu in Enugu state all in Nigeria. The water was sampled from Amanyi river which is the only source of water at Neke town in Isi Uzo local government of Enugu state.

The sawdust and diatomite were dried under air, ground into finer particles, then sieved using 180 µm (80-mesh) sieves to get diatomite and sawdust powder particles of diameter less than or equal to 180µm. The clay was prepared by crushing and soaking in water to slake for 24hrs afterwards was allowed to decant. It was thereafter poured into a POP mould to remove excess water. The semi-dry cast was left to dry in air for the whole day. The dried cast was ground to fine powder, sieved through the 180µm sieve, ready for compounding. The Plaster of Paris mould was produced from the master mould constructed.

2.2 Methods

2.2.1 Formulation of ceramic filter bodies for physical analyses

Varying percentages of sawdust and diatomite were used while clay percentage remained constant in the formulation as shown in Table 1

2.2.3 The physical analysis of the compounded bodies

The physical properties of the filters were determined and they include relative plasticity (on the clay sample), modulus of rupture, water absorption, apparent porosity and apparent density (Lynne *et al.*, 1980; and Akwilapo, 2003).

2.2.3.1 Determination of relative plasticity: The relative plasticity was determined using the cylindrical test pieces. The original height, *Ho* of the test pieces was obtained by the use of the vernier calliper by taking the average length of three sides. Afterwards, a manual plastometer machine was used to deform the test pieces. The deformation height, *Hi* was recorded by taking the average of three sides. The relative plasticity was calculated (Lynne *et al.*, 1980).

$$\text{Relative Plasticity} = \frac{Ho}{Hi} \qquad 1$$

2.2.3.2 Determination of modulus of rupture: Long cylindrical test pieces were made and air dried for 7 days after which they were oven dried at 105^0C until a constant weight is obtained. A set of four cylindrical test pieces were fired to temperatures of 850^{o}C and another set at a temperature of 950^{o}C in a kiln. The electrical transversal strength machine was used to determine the breaking load, P (Kg). A vernier calliper was used to determine the distance between supports L (cm) of the transversal machine. The height, H (cm) and the width, B (cm) of the broken pieces were determined and the average value obtained from the two broken parts was recorded. The modulus of rupture was then calculated on triplicate measurements (Akwilapo *et al.*, 2003).

$$\text{Modulus of Rupture } (\frac{\text{Kg}}{cm^2}) = \frac{3PL}{2BH^2} \qquad 2$$

2.2.3.3 Shrinkage determination

Here moulded rectangular test pieces were used. A vernier calliper was used to insert a 5cm mark on each of them; this was recorded as the original length *Lo* (cm). The test pieces were air dried for 7days and then dried in an oven at 105^0C until a constant weight was obtained. The shrinkage from the 5cm mark was determined and recorded as the dried length, *Ld* (cm). Afterwards, four of the dried samples were fired to a temperature of 850°C, and another set at a temperature of 950°C, the shrinkage of the test pieces from the 5cm mark was determined and recorded as the fired length, *Lf* (cm). The shrinkage was then calculated on triplicate measurements (Lynne *et al.*, 1980):

$$\text{Wet} - \text{Dry Shrinkage}(\%) = \frac{100[Lo-Ld]}{Lo} \quad 3$$

$$\text{Dry} - \text{Fired Shrinkage}(\%) = \frac{100[Ld-Lf]}{Ld} \quad 4$$

$$\text{Total shrinkage}(\%) = \frac{100[Lo-Lf]}{Lo} \quad 5$$

2.2.3.4 Determination of water absorption

The fired test pieces obtained after firing was weighed and the mass recorded as dry mass, M_1 (g). Thereafter, the test pieces were soaked in water for one hour, then removed, cleaned and weighed immediately and recorded as soaked mass, M_2 (g). The water adsorption was calculated on triplicate measurements (Lynne *et al.*, 1980).

$$\text{Water Absorption}(\%) = \frac{100[\text{M2}-\text{M1}]}{\text{M1}} \quad 6$$

2.2.3.5 Porosity and density determination

The suspended masses of the test pieces were determined by the use of a lever balance and recorded as M_3 (g). The apparent porosity, apparent density, and bulk density were calculated according to Akwilapo *et al.*, (2003) $\text{Apparent Porosity}(\%) = \frac{100[M_2-M_1]}{[M_2-M_3]}$ 7

$$\text{Apparent Density} = \frac{M_1}{[M_1 - M_3]} \quad 8$$

$$\text{Bulk Density} = \frac{M_1}{[M_2 - M_3]} \quad 9$$

2.2.3 Chemical Analysis

The clay and compounded samples were characterized using X-ray fluorescence spectrometer (XRF) in order to determine their elemental composition. X-ray diffractometer (XRD) was used in characterizing the clay and compounded samples in order to determine their crystallographic parameters and the effect of the compounding mixtures on the filtration ability. The diffraction was done under a wide angle range using XRD GBC EMMA powdered diffractometer with monochromatic CuKα radiation (k=1.541Å) voltage of 40kV and 40mA. The diffraction angle was scanned from 5^0 to 65^0, 2θ at a step size of 0.05^0 and a rate of 3.57^0/min. The degree of crystallinity was measured using MATCH crystal impact identification from powdered diffraction soft-ware package (version 3.4.2 Build 96) utilizing FullProof Suit program (2.05) for Rietveld Refinement. The morphologies of the compounded filter pots were investigated by SEM on a ZEISS EVO50 scanning electron microscope under the following analytical conditions: EHT = 20.00 kV, Signal A = SE1, WD = 4.0mm. The microstructure of the samples was calculated using Image J software.

2.2.4 Production of ceramic filter pot

The mix ratios as shown in Table 1 were utilized in the CPF productions using solid cast method. Each mixture was poured into a basin with 1000mls of water to dissolve. The body was vigorously mixed with a mixer in a big compounding container and then sealed with a polyethene bag for ageing (this was to improve the plasticity of the body).

2.2.4.1 Filter pressing and fettling

The formulated body was removed from the wrapped bag and kneaded on a flat table after which it was formed into balls of appropriate sizes for the specific mould. The wedged body (bodies free from air pockets) was pressed into the mould to get the pot shape using hydraulic

press machine. It is expected that the pots will have a top inside diameter of 211.6mm, and bottom inside diameter of 131.5mm while the outer diameters of the top and bottom surfaces will be 237.6mm and 157.5mm respectively. The wall thickness of the filter pot is expected to be 26.0mm. The inner height is expected to be 145.5mm while the outer height is expected to be 171.5mm. A saturated filter could then hold a maximum volume of approximately 5 litres. The water filters were allowed to undergo atmospheric drying in order to remove the water content which the mould could not absorb.

2.2.4.2 Firing and cooling of ceramic pot filters (CPFs)

The firing of the filter pots was done by loading the filters into the kiln, preheated for 30minutes at 300^{o}C, followed by slow and steady firing at 570^{o}C for one hour, then completely fired at 850^{o}C for nine hours. The fired pots were allowed to cool at room temperature for 2days after the firing had been completed. The same method described was repeated for another set of formulated CPF bodies for complete firing at 950^{o}C. The produced water CPFs were further coated with a silver solution prepared by dissolving 24g of $AgNO_3$ in 375mL of de-ionized water and allowed to air dry.

2.2.5 Water analysis

2.2.5.1 The flow rate of the CPFs

The surface area and the thickness of the CPFs were determined with a vernier calliper. The inner diameter and the outer diameter were measured. The thickness was obtained by subtracting the inner diameter from the outer diameter of the filter pot. The four CPFs were soaked in water for 24 hours to get saturated. Graduated cylinder was used to determine the volume of water filtered through the pot. 5000mL of clean water was used for all the CPFs.

The surface area and the flow rate were calculated using the mathematical formula:

$$\text{Surface area} = \frac{\pi d^2}{4} \qquad 11$$

Where d is the diameter.

The flow rate was calculated by dividing the volume of water measured in the lower container by the time taken to filter (Dies, 2003).

$$\text{Flow rate} = \frac{Volume\ of\ water\ measured(mL)}{Time\ used\ (hours)} \qquad 12$$

The selection criteria for the further water quality test were based on the results of the flow rate and as well as the result of physical properties of the CPFs. The goal of the research is to improve on the flow rate and maintain the quality of the filtrate using CPFs, thereby improving the access to potable water in the rural areas. The research is interested in the CPF that will generate the highest volume of water upon filtration, hence the selection criterion.

2.2.5.2 Water quality analysis

To evaluate the water treatment performance of CPF sample with the highest volume of filtered water, the water qualities of the water before and after filtration were measured. The physicochemical and microbial test carried out include; turbidity, pH, Alkalinity, hardness, total dissolved solids, total suspended solids, total iron and the flow rate of pot filter, total coliforms, and E coli. The analysis of the water before and after filtration was done using standard methods (WHO, 2004; and Dies, 2003).

2.2.5.2.1 Turbidity of water

The turbidity of the water before and after filtration was determined using spectrophotometer with the 'EPA 180' measurement mode.

The turbidity removal efficiency was calculated using the equation

$$\%\ Turbidity\ removal\ efficiency = \frac{\text{untreated}-\text{treated}}{\text{untreated}} \text{x}100 \qquad 10$$

2.2.5.2.2 Removal of iron, other coloured dissolved substances, and determination of silver concentration in the filtrate

The Atomic Absorption Spectrometer (210-VGT) was used to determine the iron concentration in the water before and after filtration. The concentration of silver in the filtrate from the ceramic pot filter was also determined.

2.2.5.2.3 pH and alkalinity

pH was measured by Electrometric Method Using Laboratory pH Meter Hanna Model HI991300 (APHA, 1998).

The alkalinity was calculated as follows;

$$Alkalinity = \frac{(mL\ HCl\ titrant\ )X\ (normality\ of\ HCl)\ X\ (50{,}000)}{(mL\ of\ water\ sample)} \qquad 13$$

2.2.5.2.4 Determination of total dissolved solid

The APHA 2510 A TDS 139 tester (APHA, 1998) was used to determine the Total Dissolved Solid (TDS). A clean evaporating dish was heated to 180 ±2°C in an oven for 1hr, cooled and stored in desiccators until needed. It was weighed immediately before use. A sample volume was chosen to yield between 2.5 and 200mg dried residue. 50ml of the well-mixed sample was filtered through the glass-fibre filter; washed with three successive 10ml volumes of distilled water, allowing complete draining between washings. Suction applied continually for about 3 minutes after filtration. The filtrate was transferred to a weighed evaporating dish and evaporated to dryness on a steam bath. The evaporating dish was finally dried for at least 1hr in an oven at 180 ± 2°C, cooled in a desiccator to balance temperature and weighed.

$$\text{TDS} = \frac{(A-B)\ X\ 10^3\ mg/L}{(mL\ of\ sample\ volume)} \qquad 14$$

Where A= Weight of dish+ Solids (mg)

B= weight of dish before use

2.2.5.2.5 Total coliform and the E. *coli* removal efficiency

The number of total coliforms and e. coli in a mL of water before and after filtration was determined according to the procedures in the US Food and Drug administration-Bacteriological Analysis Manual (FDA-BAM). All media were prepared according to the manufactures instruction and sterilized using autoclave at 121^{o} C for 15 minutes. The Planting method (pour planting) was used.

1mL of each of the serially diluted sample was pipette into different petri-dishes; well labelled and sterilized medium (agar) poured into each of the petri-dishes and swirled for proper

homogenization. After that, the plates were allowed to solidify, inverted and incubated for 24 hours at 37°C. Presumptive E.coli colonies on CLED agar appear differently coloured, with or without a metallic sheen. Presumptive E. coli was picked and streaked onto nutrient agar and incubated at 37°C for 24hours under anaerobic condition for purification to obtain a pure culture. Pure cultures were confirmed using gram staining E. coli latex agglutination test and biochemical tests (indole production; utilization of citrate and lactose production) (Dies, 2003).

$$\%\ Removal\ Efficiency\ = \frac{Untreated - treated}{untreated} \times 100 \qquad 15$$

Where the untreated = microbial concentration in the raw water sample (cfu/1mL)

And the treated = microbial concentration in the filtered water sample (cfu/1 mL).

3 Results/ Discussion

3.1 Physical analysis of the compounded samples

The result of the relative plasticity of the clay sample gave 1.36 ± 0.12. This shows that the clay can find usage in ceramic applications. The results of other physical analysis are shown in Table 2

From Table 2, it can be seen that water absorption and apparent porosity increased with increase in combustible materials (pore-creating agent) but decreased with temperature increase. This is attributed to the increase in pore creating materials which brought about a corresponding increase in apparent porosity and water absorption. The bulk density, modulus of rupture and dry weight, on the other hand, increased with the decrease in the combustible materials as well as with the increase in temperature. Sample A, for example, showed a decrease in water absorption and apparent porosity from 77% to 66% and 67% to 59% respectively with an increase in firing temperature from 850°C to 950°C. This was due to the increase in shrinkage and a decrease in porosity of the body as the firing temperature was increased. The bulk density and modulus of rupture for sample A, on the other hand, increased from 0.87 to 1.89g/cm^3 and 13.80 to 20.52g/cm^3 respectively with an increase in the firing temperature. As the firing temperature increases the shrinkage of the formulated body was increased as well as the strength hence,

resulting in a corresponding increase in bulk density. The water of absorption is higher at a lower temperature. This could be the change observed in the body of the filter at a higher temperature. It is expected that pores are created at high temperatures. More pores are formed when the green bodies of filters with high proportions of sawdust are fired (Mattelet, 2006 and Dies, 2003). Nevertheless, at a higher temperature also due to vitrification, which is caused by some flux agents (Na_2O, K_2O, CaO), the sealing of the pores results, thereby reducing the porosity of the filters. This varies in body or clay type. It can be said, therefore, that firing determines the porosity while porosity determines the flow rate of filters. The results show that the modulus of rupture increases with a decrease in the percentage of sawdust and increase in diatomite percentage. This was due to the removal of combustible components such as cellulose, hemicelluloses and lignin materials of the sawdust by burning off at firing temperature increase. Therefore, the more the combustible in the sample, the more components are removed, resulting in a greater space or void and compression of the body formulated during sintering and vitrification. This accounts for the decrease in the MOR and bulk density of the body as burnt out materials increase. On the other hand, diatomite is made up 85% of SiO_2 according to Table 4, which gives the strength of the material hence; increasing diatomite brings about increase in strength (MOR) and bulk density of the body during vitrification and sintering. It was observed from Table 2 that there is an increase in the linear shrinkage with an increase in firing temperature for the given samples. This is attributed to the increased burning out of organic materials as the temperature increases bringing about the closing of the void through vitrification which tends to the shrinkage of the body.

The results showed that sample A has the best physical properties determined with the best firing temperature of 850^{o}C followed by B. Hence sample A with firing temperature of 850^{o}C was adopted as the model and was used for further characterization for household water treatment intervention together with sample B.

3.2 Chemical analysis of the clay from Ukpor and the formulated ceramic pot filter (CPF)

3.2.1. X-Ray Fluorescence (XRF) Characterizations

The result of XRF analysis shows the elemental composition of the samples as presented in Table 3

From Table 3, it was shown that the clay from Ukpor contains high alumina and silica with low flux oxides (CaO, Fe_2O_3, K_2O) which makes it very suitable for refractory application such as porcelain production (white wares), floor tiles furnace lining and bricks (Fakhrul et *al.*, 2014). On the other hand, the presence of TiO_2 (rutile) in the clay showed that a vitreous body produced would have a scratching and corrosion resistant because it acts as an opacifier in the body (Lee, 1996).

The results of diatomite composition are presented in Table 4. It is seen that diatomite contains a very high percentage of SiO_2, this could bring about an increase in the strength of the filter. Presence of the Na_2O in diatomite shows that high percentage of diatomite could cause fusion of the body which at higher temperature due to sintering and vitrification would bring about pore blocking of the filter produced as well as causing a deteriorating effect on the filtration ability.

The elemental and oxide composition of the formulated sample as determined by XRF is presented in Table 5

From Table 5, it is seen that the percentage of some elements increased because of the additional effect of diatomite. From the above Tables, it can be seen that the major elemental component is SiO_2, followed by Al_2O_3. Al_2O_3 has been reported to be the major compound that prevents anti-fouling of the ceramic membrane in a filtration system (Geng and Chen, 2016; Fountoulakis *et al.*, 2016). Iron oxide (Fe_2O_3), potassium oxide (K_2O), calcium oxide (CaO) and rutile (TiO_2), were very significant in the body of the filter. It can be seen from Table 4 that diatomite is mainly composed of silica thus, brings about increase in the silica contents of the CPF sample which gave the body the extreme porosity due to the permeability nature of diatomite. This might be due to the amorphous nature of the diatomaceous silica. The potassium oxide (K_2O), calcium oxide (CaO) was observed to be higher in the compounded sample than the clay sample. These metals being low-temperature flux will bring about faster vitrification (850^oC) of the body thereby saving energy and cost.

3.2.2. X-Ray Diffraction (XRD) studies

The XRD of the sample of clay from Ukpor is shown in Figure 1. The crystallographic parameter as interpreted using MATCH crystal impact and full Prof Suit program is shown in Table 6. The XRD of the compounded body is shown in Figure 2 together with the interpretation in Table 6.

Figure 1 shows that the sample is crystalline in nature as evidenced by the sharp and distinct peaks. Table 6 identified the clay sample as dickite of kaolinite group with a chemical formula of $Al_2Si_2O_5(OH)_4$. The crystal system is monoclinic, space group 2/m (C_2h) with the following cell dimensions. $\alpha = \gamma = 90^o$ $\beta = 103.5^o$. a=5.150, b=8.940, c=14.736 Å. The result agrees with the XRF. The results of XRF and XRD of the raw clay sample showed that the sample is crystalline and contains oxides with low-temperature fluxes, scratching and corrosion resistant. XRD and XRF confirmed the clay type and the elemental composition of the body of the ceramics pot which gave a positive influence on the water treatment efficiency.

From the spectra in Figure 2, the compounded body is amorphous components since there was no sharp peak shown but a broad feature that is the hump or the halo curve. The amorphous

nature of the compounded was attributed to the fact that the sawdust and diatomite destroyed the clay crystallinity.

From the Table 6, there is a slight decrease in value of the density and increase in volume showing that more amorphous materials (sawdust and diatomite) were added when compared with the result from the clay sample.

3.3.3. SEM Analysis

The results of the SEM of CPF are shown below in Figures 3 (a) and (b).

The images in Figure 3 reveal the porous structure, an irregular surface and the particle aggregation of several shapes and sizes of the filter body. The microstructure or the pore size distribution as calculated using image J software showed a range from 0.4 to 2.95µm. This is in agreement with (Grim, 1968) report of the kaolinite pore size distribution. The opening of pores as observed was attributed to the sawdust materials (Kooli *et al.*, 2014).

The results from XRD, XRF and SEM show that the body is predominantly kaolinite clay ($Al_2Si_2O_5(OH)_4$ with two base feldspathic rocks namely anorthite $Ca[Al_2Si_2O_8]$, orthoclase $K[AlSi_3O_8]$ while albite $Na[AlSi_3O_8]$ and celsian $Ba[Al_2Si_2O_8]$ were not found in the body (Nesse, 2000). The presence of the feldspar and iron oxide could be the reason for quick vitrification of the body because they act as low-temperature fluxing agent.

The hazardous elements such as lead, mercury, arsenic, cadmium which negatively affect human health were not found as shown by XRD results. Therefore, ceramic pot is safe and suitable for water filtrations.

3.4 Water Analysis

3.4.1. The flow rate

The flow rate is one of the filter parameters that determine the performance and the quality of filters. The result of the flow rate of different compositions of the ceramic filter sample at one hour is shown in Figure 4.

From Figure 4, it can be seen that there is a steady increase in flow rate with increase in burnt out materials (sawdust). The increase in porosity brings about a corresponding increase in flow rate as the filter pores are increased by raising the proportion of sawdust. From the graph above, the higher the percentage sawdust the higher the porosity or pores of the filter then the higher the flow rate of a filter. At 65% sawdust the pot filtered at the rate of 2.5L/h while at 60%, 50% and 45% the pot filtered at the rate 2L/h, 0.20L/h, and 0.06L/h respectively. Consequently, Sample A, with the highest apparent porosity of 67% and water absorption of 77%, together with Sample B, with an apparent porosity of 62% and water absorption of 69%, were used for further water quality test. Sample A, equally gave the highest volume of filtered water with a close match from that of sample B. These are in agreement with the goal of the research of improving the flow rates of CPFs.

3.4.2 Water quality test

In Table 7 is shown the physicochemical parameters of the water quality analysis before and after filtration.

From the result, the quality of the filtered water compared well with WHO standard and gave favourable removal efficiencies in terms of turbidity, total iron, total suspended solids, total coliform and E coli.

3.4.1. pH, alkalinity and total hardness

The water samples, before and after filtrations (A and B) revealed pH of 5.76, 6.76 and 7.48 respectively. The pH of the treated water was observed to have increased by 1. This could be as a result of an increase in the alkalinity of the filtrate. The pH of filtered water is within WHO specifications (pH> 6.5). There is an increase in the alkalinity of the treated; this could be as a result of the clay from Ukpor which contains alkaline and alkaline earth metal oxides such as

K_2O, Na_2O and CaO. The total alkalinity is within the permissible limit of WHO which is 200 mg/L.

3.4.2. Iron content

Iron does not have an adverse effect on the human system but the presence brings about aesthetic problems, an increase in the turbidity and the taste of the water. The WHO standard for the iron content in the water is within 0.3mg/L. Table 7 shows that the CPFs were able to reduce the iron content of Amanyi river to WHO specification. According to WHO, (2004), Iron is usually not detectable by users below 0.3 mg/L. The result agreed with the result given by Chukwurah (2003), who attributed the efficiency of iron removal to be due to the aeration process during the pouring of the water sample in the CPF, thereby changing the iron from iron II to iron III and the precipitate trapped by the filter medium and hence making the filtered water potable.

3.4.3. Turbidity

The turbidity of the Amanyi is excessively high, this could be because of the high level of activities going on in the river like washing, swimming and packing of sand from the river by tipper drivers. From Table 7, the turbidity of the water sample from the river is 68 NTU while that of the filtered water samples were reduced to 4.8 NTU which corresponds to 93% turbidity removal efficiency in sample A and 4.1 NTU which corresponds to 94% turbidity removal efficiency in sample B. The treated water turbidity levels are within the WHO's recommended limit of drinking water of 5.0 NTU (WHO, 2004). Hence the treated Amanyi water met WHO limit for turbidity level. This result compared well with Isikwue (2010) who evaluated the performance of locally made ceramic pot as a water purification system. He observed that the turbidity of the unfiltered water sample was 49.0 NTU while the turbidity level in all the filtrate ranged from a minimum value of 3.0NTU to a maximum value of 30.0 NTU.

3.4.4 The total dissolved solids (TDS)

The total dissolved solid expresses the total amount of dissolved metals and all the other inorganic materials in the water. The filtered and unfiltered water samples from Amanyi river gave 1.94600mg/L (sample A), 1.32420mg/L(sample B) and 5.42600mg/L respectively. This is below the recommended WHO standard maximum of 600mg/L. Water whose TDS is above 600 mg/L

is considered to be unpalatable for drinking. The result agreed with that of Bolaji *et al.*, (2013) whose result was 4 to 25 mg/L after passing through their ceramic filter.

3.4.5 Total suspended solids (TSS)

The results of the TSS before and after filtration were 2.48 mg/L, 0.94mg/L(sample A) and 0.67mg/L(sample B), respectively. The result confirms the ability of the CPFs to reduce suspended solid.

3.4.6 The Silver concentration in the filtrate

The results of the silver concentration of the filtrates were 0.0102 mg/L (sample A) and 0.0015mg/L (sample B). This is within the WHO's guidelines for drinking water quality (WHO, 2004) which indicated a guideline of 180µg/day for the concentration of silver ion in drinking water three litres per a day (Oyanedel-Craver V *et al.*, 2014). The result compared well with Lamichhane and Kansakar, (2013) who compared the performance of three different types of ceramic filter candles (MCC, Puro, and Surya) in treating drinking water. The filter candles performance with or without colloidal silver (CS) coating was determined based on flow rate, E. *coli* removal efficiency and total coliform removal efficiency. The E. *coli* removal efficiency of MCC candle was 39% to 60% without CS coating while it was 69% to 77% with CS coating.

3.4.7 The microbial analysis test

In Table 7 shown is shown the result of microbial analysis for coliform and *e coli* in water samples before and after filtration. The result reports, 6 coliforms/mL and 10 e *coli*/mL for the water sample before filtration while 0 (zero) coliform/mL and 0 E.coli/mL after the water filtration. These results have proved that the filter can remove the microorganism to 100% efficiency. It met WHO standard of 0 coliform/100mL and 0 E.coli/100mL. This was as a result of the silver nitrate applied to the ceramic filter pot. According to Lantagne (2001), microbial removal cannot be complete unless colloidal silver was applied to the filter (Mikelonis *et al.*, 2016). Molly, (2009) also observed that silver had an additional benefit of preventing the growth of a biofilm in the plastic storage container.

According to Molly (2009), once the percentage of sawdust is greater than 60%, the microbial removal efficiency is affected negatively because an increase in flow rate leads to decrease in microbial reduction efficiency (Wongsakoonkan *et al.*, 2014). The result is in agreement with Olubayode *et al.*, *(*2016) who characterized some selected clay in Nigeria for the purpose of ceramic water filter. Their results revealed that as the volume ratio of sawdust increases these properties (water absorption, linear shrinkage, and compressive strength) of the clay decrease. Hence filter B is adjudged the best filter produced with respect to microbial reduction while in terms of flow rate sample A is preferred. Sample A and B proved better results with respect to Fakhrul et *al.*, (2014) who developed ceramic candle filters by slip casting process, and fired at a temperature of 1100^{o}C. In their study, diatomaceous earth was used as a pore-forming agent in clay and was varied at constant clay proportion. However, 25% of diatomaceous earth was used. Microbial removal efficiency was found 99.99% with a flow rate of 675 mL/hour.

4 Conclusions

In this work, the combination of Ukpor clay, sawdust, and diatomite in the right proportion proved to be very effective in water treatment. The water absorption and apparent porosity increase with an increase in combustible materials and decrease with temperature. The bulk density, modulus of rupture and dry weight on the other hand increase with a decrease in the combustible materials and with an increase in temperature. The result of the flow rate showed that the flow rate increased with an increase in the percentage of sawdust to the mixture. The results also showed that sample A has the best physical properties determined with the best firing temperature of 850^{o}C followed by B. It was observed that CPF sample A was extremely porous and high in modulus of rupture; this could be attributed to diatomite. It provides high porosity, high surface area, inertness, high absorptive capacity because of high silica content and thus increases flow rate without compromise in the removal efficiency. The CPF sample B was equally able to remove total coliform, Escherichia coli, iron content, colour dissolved substances, total dissolved solids (TDS) and total suspended solids (TSS) to the recommended values for drinking water while the flow rate of 2L/hr was obtained. The pH of the treated water was improved from 5.78 to 6.76 in sample A and 7.42 in sample B which are within the range of WHO standard. The results of the removal efficiencies for turbidity, total dissolved solids, total

suspended solids, e coli, and coliform gave 93%, 64%, 62%, 100% and 100% respectively for sample A and 94%, 77%, 72%, 100% and 100% respectively for sample B. The results obtained show that the CPFs produced with emphasis on the 65% sawdust, 25% clay and 10% diatomite(A) and 60% sawdust, 25% clay and 15% diatomite(B) mixtures met the WHO standard for safe drinking with sample A having a higher flow rate. The results confirmed the suitability of the materials locally sourced for the production of ceramic water filter pots which were able to treat water to WHO standards. This implies that the inherent problems of water-borne diseases prevalent in rural communities due to inaccessibility to supply of good quality and clean water could be solved by introducing them to the use of ceramic water filter pots produced by the mixtures of clay, diatomite, and sawdust.

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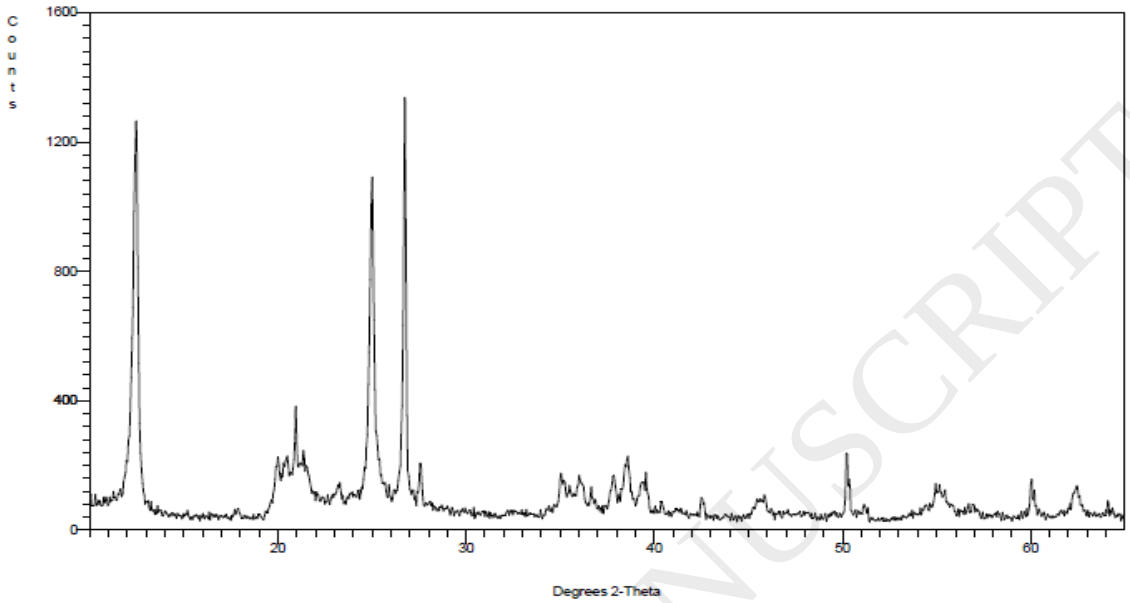


Fig. 1: X-Ray pattern of clay from Ukpor sample (clay sample before compounding)

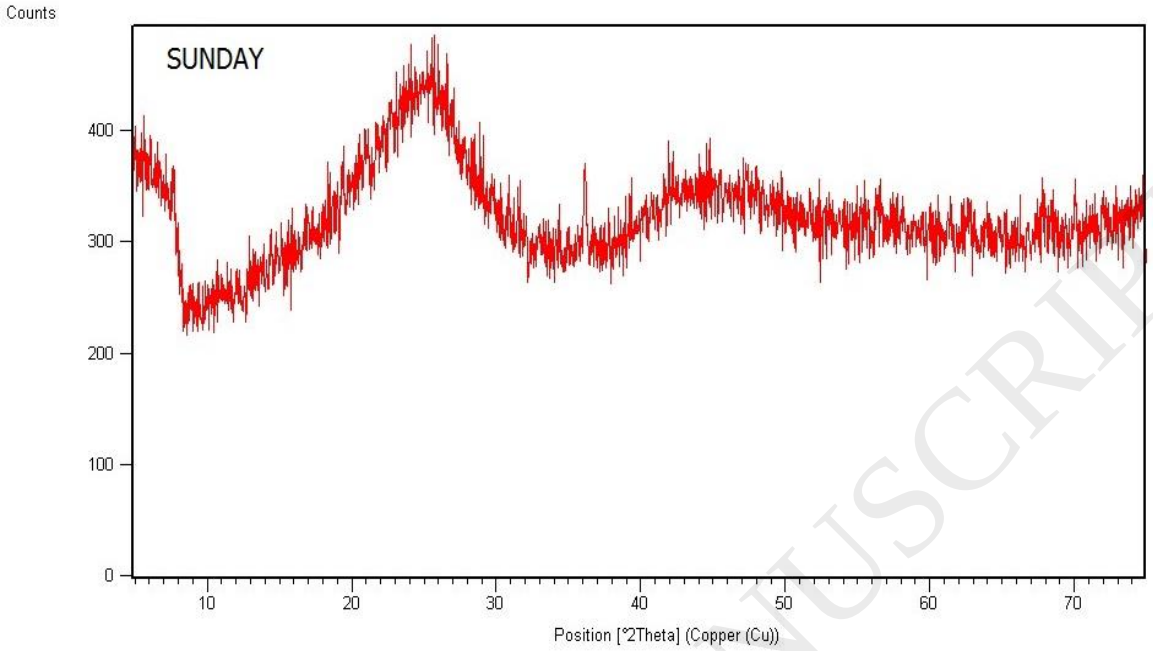
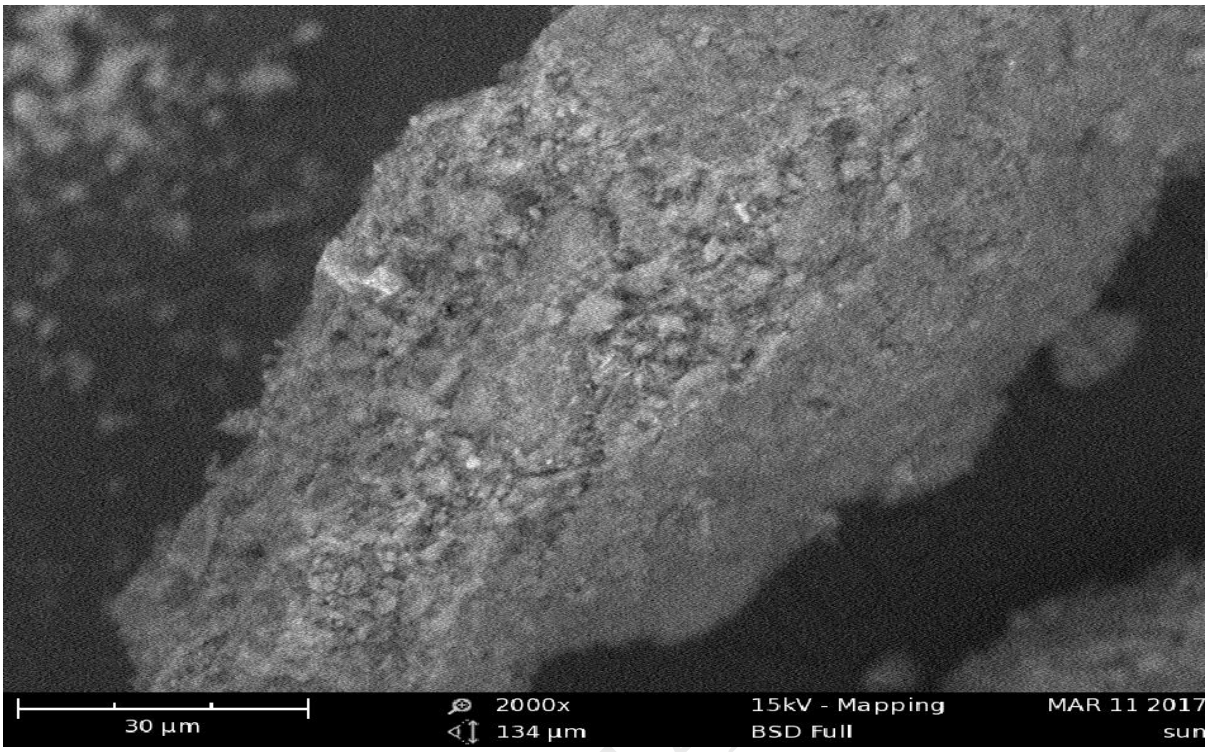
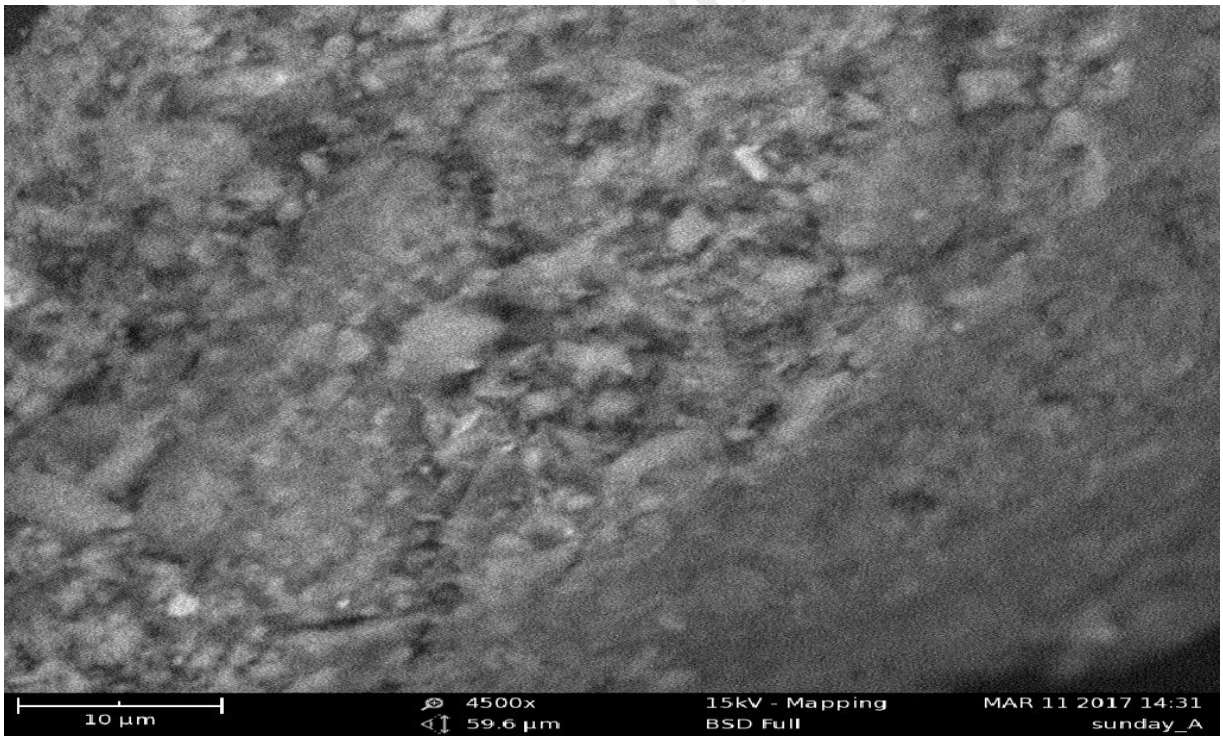


Fig. 2: The X-Ray Diffractogram of the formulated pot filter (Sample A)



a)



b)

Fig. 3 (a) and (b): SEM micrograms of the produced filter body sample at a different magnifications

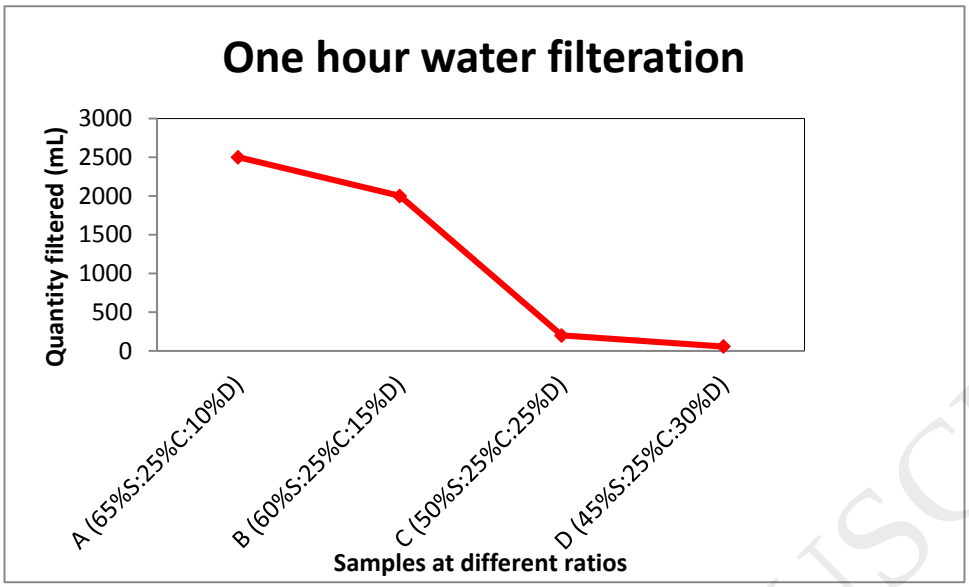


Fig. 4: The Flow rate of different samples at a given hour

Table 1: Formulation of the ceramic pot filter bodies

Sample code	Clay%	Sawdust%	Diatomite%
A	25	65	10
B	25	60	15
C	25	50	25
D	25	45	30

Table 2: The summary of the physical analysis of Ceramic pot filter at 850ºC and 950ºC

Parameter	**850ºC**				**950ºC**			
	A_1	B_1	C_1	D_1	A_2	B_2	C_2	D_2
Water absorption (%)	77 ±2.25	69 ± 2.15	52 ±2.05	35 ±2.12	66 ±2.13	58 ±2.10	47 ±2.01	31 ± 2.02
Apparent porosity (%)	67 ± 0.05	62 ±0.16	52 ±0.19	44 ±0.08	59 ±0.01	54 ±0.07	48 ±0.12	38 ±0.23
Apparent density g/cm^3	2.65 ±0.02	2.25 ±0.02	2.18 ±0.03	2.26 ±0.00	2.16 ±0.01	2.02 ±0.01	1.81 ±0.03	1.23 ±0.01
Bulk density g/cm^3	0.87 ±0.01	0.90 ±0.00	1.08 ±0.01	1.27 ±0.00	1.89 ±0.00	1.93 ±0.01	2.18 ±0.00	2.02 ±0.02
Modulus of rupture g/cm^2	13.80 ±0.05	14.03 ±0.01	14.70 ±0.08	15.12 ±0.00	20.52 ±0.06	30.20 ±0.06	35.32 ±0.07	46.34 ±0.03
Dry mass, M_1 (g)	48.23 ±2.25	52.14 ±2.15	52.30 ±2.05	53.50 ±2.12	49.40 ±2.13	51.70 ±2.10	57.40 ±2.01	57.75 ±2.02
Soaked mass, M_2 (g)	85.40 ±2.25	86.52 ±2.15	88.20 ± 2.05	84.60 ±2.12	75.07 ±2.13	70.05 ±2.10	77.24 ±2.01	75.70 ±2.02
Wet- Dry shrinkage (%)	2.40 ±0.01	2.20 ±0.02	0.80 ±0.02	0.80 ±0.01	2.80 ±0.01	1.60 ±0.00	1.20 ±0.01	1.00 ±0.10
Dry- Fired shrinkage (%)	2.25 ±0.01	1.64 ±0.02	2.42 ±0.02	1.81 ±0.01	2.26 ±0.01	2.85 ±0.00	1.82 ±0.01	2.02 ±0.01
Total shrinkage (%)	4.60 ±0.01	3.80 ±0.02	3.20 ±0.01	2.60 ±0.01	5.00 ±0.18	4.40 ±0.06	3.00 ±0.10	3.00 ±0.20

Table 3: XRF result showing the composition of clay sample from Ukpor

Elements	Weight (%)	Oxide form	Weight (%)
Si	23.265	SiO_2	49.76
Al	21.12	Al_2O_3	39.91
Fe	0.98	Fe_2O_3	1.40
P	0.34	P_2O_5	0.88
S	0.42	SO_3	1.04
K	1.42	K_2O	1.71
Ca	0.087	CaO	0.12
Ti	0.78	TiO_2	1.29
V	0.058	V_2O_5	0.10
Cr	0.01	Cr_2O_3	0.01
Mn	0.04	MnO	0.05
Ni	0.07	NiO	0.10
Cu	0.07	CuO	0.08
Zn	0.12	ZnO	0.15

Table 4: Oxide composition of diatomite sample

Oxide form	Weight %
SiO_2	85.38
Al_2O_3	2.90
Fe_2O_3	2.57
K_2O	0.90
CaO	0.42
TiO_2	0.32
MgO	0.32
Na_2O	2.51

Table 5: Elemental and Oxide Composition of the formulated Sample using X-Ray Fluorescence (XRF)

Elements	Weight (%)	Oxide form	Weight (%)
Si	26.85	SiO_2	57.43
Al	20.82	Al_2O_3	39.34
Fe	1.72	Fe_2O_3	2.63
K	1.36	K_2O	1.64
Ca	0.64	CaO	0.90
Ti	0.90	TiO_2	1.50
V	0.04	V_2O_5	0.08
Cr	0.03	Cr_2O_3	0.02
Mn	0.14	MnO_2	0.23
Zn	0.17	ZnO	0.21
Na	1.47	Na_2O	1.98

Table 6: XRD parameters of clay from Ukpor and compounded filter body

Lattice parameters	Raw clay	Compounded filter body (Sample A)
a (Å)	5.1500	5.1610
b (Å)	8.94000	8.9600
c (Å)	14.7360	14.4590
α^o	90.000	90.000
β^o	103.580	96.770
γ^o	90.000	90.00
Density	2.558g/cm^3	2.483g/cm^3
Volume (A^3)	659.8387	663.9591cm^3
Empirical Formula	$Al_2H_4O_9Si_2$	
Chemical formula	$Al_2Si_2O_5(OH)_4$	
Number per unit cell	$Al_8H_{16}O_{36}Si_8$	
Molecular weight	258.16	
Clay group	kaolinite	
Mineral Name	dickite	
Compound name	Auminum silicate hydroxide	
Space point group	2/m	
Bravais lattice	C	
Crystal System	Monoclinic	

Table 7: The result of the water quality test before and after filtration using sample A.

Parameter	Unit	Before	After Sample A	After Sample B	Removal Efficiency (%) of A	Removal Efficiency (%) of B	WHO Standard
Turbidity	NTU	68	4.8	4.1	93	94	5
pH	….	5.78	6.76	7.42	…..	…..	6.5 – 8.0
Alkalinity	mg/L $CaCO_3$	50	55	70	…..	…..	<200
Total Iron	mg/L	0.655	0.366	0.345	44	47	0.3
Total Silver	mg/L	---	0.0102	0.0015	…..	…..	180µg/day
TDS	mg/L	5.42	1.94	1.32	64	77	<600
Total Hardness	mg/L $CaCO_3$	64	120	123	…..	…..	<200
TSS	mg/L	2.48	0.94	0.67	62	72	<600
Total Coliform	CFU/mL	6	0	0	100	100	0
E. Coli	CFU/mL	10	0	0	100	100	0