Suitability of using Ado Ekiti, Akerebiata (Ilorin) and Birni Gwari (Kaduna) Clays for Production of Household Ceramic Water Filter

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Abstract
Access to safe water is a great problem faced by the average Nigerian, which has resulted to different forms of diseases. The use of ceramic water filter (CWF) has been found useful and effective to address this problem in some developing countries like Cambodia, Mexico Ghana, Songhai, China and India. This study is aimed at investigating the suitability of some Nigerian clays for production of CWF. Three Nigerian clay samples were obtained from Ado-Ekiti, Akerebiata-Ilorin and Birni-Gwari. The samples were prepared and their physico-chemical properties were analysed. Variety of CWF were produced using each of the clay sample mixed with different combustible and incombustible additives (silica sand, sawdust, rice husk and charcoal) in different proportions. The properties and efficiencies of filters were examined. The results showed that the tested clay samples belong to alumino-silicate group. 20 – 30 % proportion of addition in the clay-additive generated adequate pores suitable to produce qualitative and quantitative safe water from the developed CWF. The CWF from Akerebiata-Ilorin and Ado-Ekiti clay samples were suitable and effective to produce safe water. The information on the most suitable filter in this study can be used to produce effective filter with large sizes for individual or group use.

Keywords: *alumina-silicate, charcoal, purification, rice-husk, sawdust*

1.0 INTRODUCTION

For many decades now, huge amount of money has been budgeted annually by government of Nigeria at all levels (Hussaini, 2009), for provision of portable drinking water. Yet, people, most especially, in the rural areas do not feel the impact. Lack of access to portable drinking water has led to several health challenges in the country. Shuaib-Babata (2015) asserted that lack of access to portable drinking water has made thousands of Nigerians to face problems of one disease or the other, such as guinea worm and diarrhoea. Individuals at their own levels have also made several efforts to proffer solution to this problem. Part of these efforts includes: provision of water in sachets and bottles for commercial purpose, drilling of bore holes by government and individuals. Yet, the problem has not been fully solved. Presently, Water Corporations of different States as well as municipal water supply by Local Government Areas in Nigeria could not meet people's demands in term of portable water supply. The cause of this predicament is attributed to corruption in various governmental agencies responsible for water processing and epileptic nature of electricity supply in Nigeria. Adequate electricity supply is essentially required for processing and supply of portable water supply to various homes by these bodies.

Worldwide, water covers about 70% of the earth, out of which only 1% is available for drinking (American Water Works Association, 2016). Water as an essential commodity is needed by human being and other animals to aid food digestion and regulate their body temperature. For human consumption, water has to be portable, free of pollutants or contain an acceptable level of the pollutants. In Nigeria, water is abundantly available in rivers, springs and other water sources, but contains several contaminants, such as organic and inorganic pollutants, and microbiological contamination, majorly from *faeces*. Meanwhile, to make water suitable for consumption, there is need for water purification. Most available water purification devices, especially ceramic water filters in Nigeria are imported into the country, which are not readily available and expensive. Factually, there is no mechanism in place for providing safe and affordable drinking water to majority of the Nigeria population, especially for people living in the rural areas. Even the fad called “pure water” ended up providing unsafe drinking water glamorised in cellophane packets and plastic bottles. Research reliably revealed that the majority of the water treatment devices are associated with problem of poor construction, operation and maintenance of water systems (Lenntech, 2011; Nakate *et al*., 1996; Rosidiaah *et al*., 2017 and State Hygienic Laboratory, 2017). More so, production of most water filtration devices (filters) involves complex design; it ends up at producing poor device due to lack of adequate equipment.

Clay has been used successfully to produce filters, which were effectively used in several places, like Cambodia, Mexico Ghana, Songhai, China, India, Tanzania, Nicaragua and Pakistan, to produce safe drinking water (RDIC, 2009). In Northern Ghana, clay was used to produce ceramic water filter, locally known as “kosim filter”.

2.0 MATERIALS AND METHOD

2.1 Collection and Preparation of Raw Materials

Clay samples were obtained from Ado Ekiti (Ekiti State in Western region of Nigeria), Akerebiata-Ilorin (Kwara State in North-Central region of Nigeria) and Birni Gwari (Kaduna State in North-West region of Nigeria). The additives used in this study were combustible materials (sawdust, rice husk and charcoal) and incombustible material (silica sand), which were locally obtained within Nigeria.

Rice-husk, which is normally regarded as a waste in rice milling industry, was collected in a local rice-milling outfit in Iworoko-Ekiti. The sawdust from *Mahogamy* tree (for uniformity and because of its availability) was also collected from ‘Aba Oyinbo’ (a sawmill industry at Ado-Ekiti). The charcoal from burnt *Mahogamy* tree was also obtained from a village at Ado-Ekiti. The silica sand was collected from the Mid-stream of Asa River in Ilorin.

Every unwanted inclusion, which is normally found in clay particles and the additives right from the sites of collection, such as stones, grasses, roots, and organic matters were carefully separated manually (hand-picked), The sorted samples were left in the atmosphere for five (5) days to reduce the materials’ moisture contents. Rough crushing of the bulk clay samples was carried out with the use of simple devices like hammer, hand crusher and later in a mortar. The materials were sieved severally, using sieves of different sizes (1.18 mm, 1.02 mm, 750 µm and 75 µm aperture sieve to obtain fine aggregates. The sieves were orderly arranged with 1.18 mm on top and 75 µm at the bottom.

2.2 Characterisation of Clay Samples

The physico-chemical properties of the clay samples were investigated for characterisation of the clay.

2.2.1 Chemical analysis

The samples were analysed using Atomic Absorption Spectrometer (ASS) for the chemical composition of the clay samples at Federal Institute of Industrial Research, Oshodi, Lagos (FIIRO).

2.2.2 Laboratory testing of clay samples

The different properties of the clay samples such as grain size, moisture content, Atterberg Limit/Consistency Tests (liquid limit, plastic limit, plasticity index and hydrometer analysis), permeability, bulk density, porosity, specific gravity, and crushing strength were investigated using British Standard (BS 1377:1975) as described by Mittal and Shukla (2003).

2.3 Production of clay- additive mix (filter)

The materials (clay and the additives) were weighed in various proportions stated in **Table 1**, mixed and tempered and then thoroughly blended with addition of adequate quantity of water to ensure products of uniform composition and uniform distribution of fine and coarse grains.

Table 1: **Proportion of clay and additives in forming the raw filter mixes for the production of filters**

S/N	Proportion of clay (%)	Proportion of additives [each of sawdust/charcoal or silica sand] (%)
1	100	0
2	90	10
3	80	20
4	70	30

Each of the raw filters mixed produced from the mixture of clay and the additives as stated in **Table 1** was moulded into disk-shape unfired filter with thickness of 1.5 cm and diameter of 6 cm. This was done with the use of hydraulic press. The compaction force of 190 KN was used as recommended by Rivera (Kabagambe, 2010). The green body was dried in still air at room temperature for a day and later dried in oven at 100 ^{o}C for three hours to remove moisture. **Plate 1** shows disk-shape filters with different material compositions.

Plate 1: Disk-shape filters with different material compositions

The unfired filters were packed at room temperature into a drying kiln, which was slowly heated for two hours to attain a temperature of 450 ^{o}C to avoid warpage or cracking. Proper firing was then carried out at 900 ^{o}C in a kiln for five hours to burn off the combustible material in the sample. The firing temperature was maintained for another one hour to attain homogenous transformation of heat within the samples. Temperature of 900^{o}C was found suitable for efficient production of ceramic with Nigerian clay in the preliminary experimental analysis of this study. The samples were oven cooled for 9 hours to avoid damage of the samples.

2.4 Experimental measurements of filters' properties

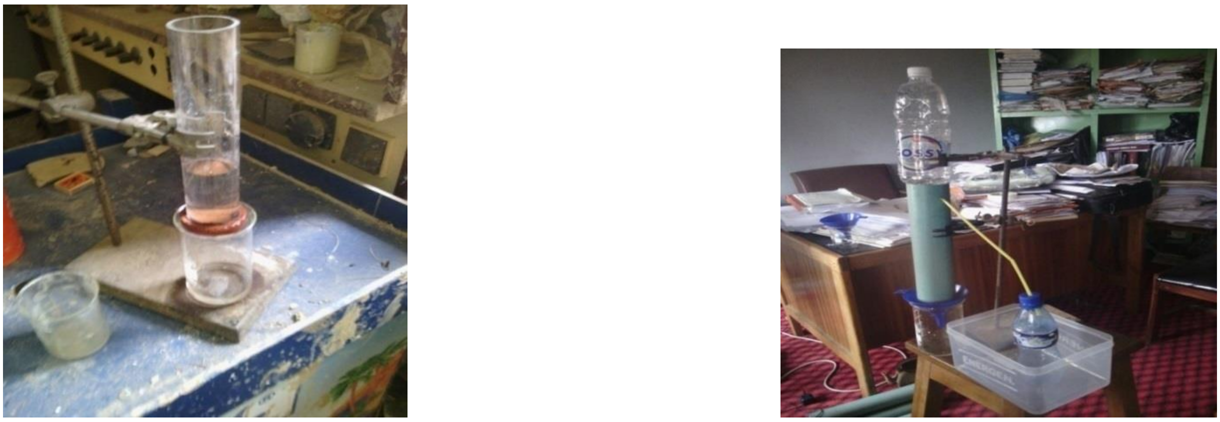
Various parameters were measured from the filters in accordance with the British Standard (BS 1377:1975) procedures (Mittal ad Shukla, 2003; Brain and Johns, 1978). The parameters include porosity, permeability of water, linear shrinkage, water absorption, flow rate, bulk density, and strength.

2.5 Filtration system

In preparation for the effectiveness tests of the fired filters, each filter was fitted unto a cylindrical PVC pipe/glass tube to set up a filtration system as shown in **Plates 2 and 3**.

The filtration system comprises of upper chamber and lower chamber. The upper chamber houses untreated water and the filter, while the lower chamber houses filtered water. The filtration system is shown in **Plate 3.**

Plate 2: Assemblies filtration system



(a) Filtraion system with glass as storage device (b) Filtraion system with PVC as storage device

Plate 3 (a) and (b): Filtration systems

2.6 Testing for effectiveness of ceramic water filter

The effectiveness of the disk-shaped ceramic water filters made from the selected Nigerian clay materials was tested by collecting raw (untreated) water from a pond within the main campus of the Federal Polytechnic, Ado-Ekiti (shown in **Plate 4**) with the use of a clean white plastic container, and filtered through the various filters. The laboratory examinations to determine the quality/properties of raw and filtered water were carried out at the Central Laboratory (Chemistry and Micro-Biology units) of the Department of Science Laboratory, Federal Polytechnic, Ado-Ekiti. The quality of water such as the percentage of turbidity, percentage of total *coliforms* and total dissolved solids in the water before and after filtration process were determined.

(a) **Source of raw water (pond)**

(b) Raw water collected from the pond

(c)

(d)

Samples of filtered water

Plate 4 (a)-(d): Source of raw water; water samples before and after filtration through the filtration system

The microbial analysis of the water to determine total *coliforms* in the water samples was carried out using plate count method (technique) to determine the bacterial efficiency of the filters. The total dissolved solid (TDS) in the water samples was also determined using 139 TDS tester shown in Plate V and recorded. The levels of TDS in the water samples in Part per million (mg/l) were also determined. Percentage efficiency of the filter in removing total dissolved solids / Total *coliform*/Turbidity was calculated using Eq (1).

$$\% \text{ Removal Efficiency} = \frac{\text{Raw water sample value} - \text{Filtered water sample value}}{\text{Raw water sample value}} \text{ x } 100 \quad (1)$$

TDS meter

TDS and other testing apparatus

Plate 5: Set of tools for water analysis

The flow rates of the ceramic water filters were also determined using the relation in Eq. 2 (Shuaib-Babata, 2015).

$$Flow\ Rate = \frac{\text{Volume of filtered water}, V_f}{\text{Period taken to filter the water, T}}, \left(\frac{\text{ml}}{\text{hour}}\right) \quad (2)$$

Each of filter's percolation rate, which is flow rate per unit area, a better measure independent of size of filter was also calculated. Percolation rate of water was also determined using Eq. 3 (Shuaib-Babata, 2015).

$$P = \frac{V_f}{A \times t_t} \quad (3)$$

where: P is the perforation rate, ml $(hr.)^{-1}(cm)^{-2}$, V_f is the volume filtered, A is the surface area of the filter, t_t is the time of filtration, and d is the diameter of the filter

3.0 RESULTS AND DISCUSSION

The results of the chemical characterisation of the raw materials and the physical and thermomechanical properties of the produced filters are presented in **Tables 2 – 4** and **Figures 3 – 6.**

The results of chemical analysis in **Table 2** show that the major constituents of the clays (more 70 %) are silica (SiO_2) and alumina (Al_2O_3). Therefore, the clays belong to alumino-silicate group. SiO_2 and Al_2O_3 in the clay samples are fairly stable ranging from 45.58 % to 47.61 %, and 24.66 % to 34.70 % respectively. The values of flux oxides in the raw clay samples also varies, which can be attributed to contamination from the impurities available at the various locations where each of the clay samples were obtained.

Table 2: Chemical composition of the selected clay samples

S/N	Clay Samples	SiO_2	Al_2O_3	TiO_2	Fe_2O_3	CaO	MgO	Na_2O	K_2O	LOI	Classification
1	Ado-Ekiti	46.00	24.66	0.11	18.31	4.28	3.62	0.014	0.015	3.00	Red Clay
2	Akerebiata	45.58	34.40	0.87	0.61	0.07	0.08	0.04	0.20	17.77	Black/Ash
3	Birni Gwari	47.61	34.70	1.23	0.37	0.13	0.10	0.23	0.60	15.00	Grey White

The appearances of the raw clay samples were in major three colourations; namely red colour, black/ash colour and white colour for Ado Ekiti clay sample, Akerebiata clay sample and Birni Gwari clay sample respectively. The reddish colour can be attributed to the presence of iron oxide in accordance with Huber (1985) that sometimes iron containing minerals could be part of the kaolinite. The iron oxide concentration ranges from 0.31 to 18.3 %. The higher values of Fe_2O_3 in Ado Ekiti clay sample reflect its reddish colour. The slight blackish colouration in Akerebiata clay sample can also be due to the presence of carbonaceous (organic) matter (like vegetable). Other fluxing agents (impurities) in the clay such as CaO, MgO, K_2O and Na_2O, were within the acceptable ranges (Kirabira, 2005) and fall within the clay group kaolinite (alumino-silicate). However, it is of the view that impurities, such as CaO, MgO, Na_2O, $CaSO_4$, $CaCO_3$, MnO_2, P_2O_5, Fe_2O_3 and TiO_2 in an ideal kaolinite should be in small quantities.

The values of the constituents of Nigerian clay samples derived from the chemical analysis carried out were within the recommended values for either refractory materials or ceramic, similar to commercial filter clay, Ntaawo (Uganda) clay and Seeta (Uganda) clay. **Table 3** shows various chemical compositions of natural materials used for the production of clay – additive mixes (filters).

Table 3: Chemical composition of combustible materials and silica sand used as additives

S/N	Additives	SiO_2	Al_2O_3	TiO_2	Fe_2O_3	CaO	MgO	Na_2O	K_2O	LOI/Others
1	Silica sand	81.6	2.35	0.08	0.91	5.50	0.86	0.0118	0.020	-
2	Rice husk	65.3	3.98	-	0.60	1.47	2.78	1.82	2.46	18.88

Source: Kabagambe (2010)

3.1 Assessment of the clay samples' physical and thermomechanical properties

The summary of the properties of the clay samples obtained from various experimental tests and literatures are presented in **Table 4**.

Table 4: The physical and Thermo mechanical Properties of the produced ceramic water filter

S/N	Clay sample	Atterberg limit: Liquid Limit (LL) %	Plastic Limit (PL) %	Plastic Index (PI) %	Linear Shrinkage (%)	Particle Distribution (% Clay Contents)	Porosity (%) X10^{-3}	Bulk Density (g/Cm^3)	Permeability (X 10^{-5} cmsec^{-1})	Cold Crushing Strength (N/mm^2)	Moisture Content	Specific Gravity	Refractoriness (°C)
1	Ado-Ekiti	82.3	33.7	48.6	6.0	90.90	25.79	1.66	83	186	22.3	2.73	>1300
2	Akerebiata	77.7	25.1	52.6	10.8	98.00	31.76	2.34	82	881	27.3	2.51	>1300
3	Birni Gwari	58.0	21.6	36.4	10.3	54.50	21.3	1.73	81	173.1	21.0	2.90	>1300
4	Nigerian Commercial Ceramic Water Filter	ND	ND	ND	ND	ND	25.9	1.0	ND	ND	ND	ND	ND
5	Seeta (Uganda) Filter A (Kabagambe, 2010)	ND	ND	ND	ND	ND	42.67	ND	ND	ND	ND	ND	ND
6	Seeta (Uganda) Filter B (Kabagambe, 2010)	ND	ND	ND	ND	ND	43.79	ND	ND	ND	ND	ND	ND
7	Ntaawo (Uganda) Filter A (Kabagambe, 2010)	ND	ND	ND	ND	ND	39.41	ND	ND	ND	ND	ND	ND
8	Ntaawo (Uganda) Filter B (Kabagambe, 2010)	ND	ND	ND	ND	ND	40.87	ND	ND	ND	ND	ND	ND

ND – Not determined

The physical and thermomechanical properties of the ceramic water filter produced from Ado-Ekiti, Akerebiata and Birni Gwari clays compared favourably with commercial filters available in the markets as well as other filters produced from Uganda's clays.

The result of the sieve analysis of the clay in **Table 4** indicates that the samples of clay fall within silt-clay materials as their clay contents are greater than 35 % in line with

American Association of State Highway and Transportation Officials (AASHTO) classification of soils and Soil-Aggregate Mixtures shown in **Table 5** (Emesiobi, 2000).

Table 5: American Association of State Highway and Transportation Officials (AASHTO) classification of soils and soil-aggregate mixtures, with suggested subgroups

AASHTO DESIGNATION M145											
GENERAL CLASSIFICA-TION	GRANULAR MATERIALS (35% OR LESS PASSING NO. 200 SIEVE)							SILT-CLAY MATERIALS (MORE THAN 35% PASSING NO. 200 SIEVE)			
	A-1			A-2							
GROUP CLASSIFICATION*	A-1-a	A-1-b	A-3	A-2-4	A-2-5	A-2-6	A-2-7	A- 4	A-5	A-6	A-7-6
	SIEVE ANALYSIS: % PASSING:										
NO. 10 (12.00mm)	50 MAX.										
NO. 40 (0.425mm)	30 MAX.	50 MAX.	15 MIN.								
NO. 200 (0.075mm)	25 MAX.	10 MAX.	35 MAX.	35 MAX.	35 MAX.	35 MAX	36 MIN.	36 MIN.	36 MIN.	36 MIN.	
CHARACTERISTICS OF FRACTION PASSING NO. 40 (0.425mm)											
LIQUID LIMIT				40 MAX.	41 MIN.	41 MIN.	40 MAX.	41 MIN.	40 MAX.	40 MIN.	
PLASTIC INDEX		6 MAX	NP	10 MAX.	10 MAX	11 MIN	11 MIN	10 MAX	10 MAX	11 MIN	11 MIN
GROUP INDEX		0	0		4 MAX			10 MAX	10 MAX	16 MAX	20 MAX
USUAL TYPES OF SIGNIFICANT	STONE FRAGMENTS, GRAVEL AND SAND		FINE SAND		SILTY OR CLAYEY GRAVEL AND SAND				SILTY SOILS	CLAYEY SOILS	
GENERAL RATING AS SUBGRADE	EXCELLENT TO GOOD									FAIR TO POOR	

Source: Emesiobi (2000)

The liquid limits of the clay samples were greater than 50 %. This analysis reveals that the clay samples studied belong to high plasticity clay. According to the plasticity chart (**Figure 2**), liquid limit of a clay sample above 50 % is an indication that the clay is of high plasticity and therefore belongs to either inorganic silts or organic clay with compressibility. Higher value of liquid limit of clay indicates high compressibility of the clay (Emesiobi, 2000). Also, high plasticity of the clay samples is an indication that the clays may belong to kaolinite or illite group. Reduction in the value of plastic index increases permeability and decreases compressibility*.* According to Cansagrande chart (**Figure 1**), clay with Plastic Index less than or equal to 10 % and liquid limit less than or equal to 30 % is of low plasticity (Emesiobi, 2000). Illustration of the relationship between plastic index, plasticity, compressibility and Liquid limit is shown **Figures 1 and 2**.

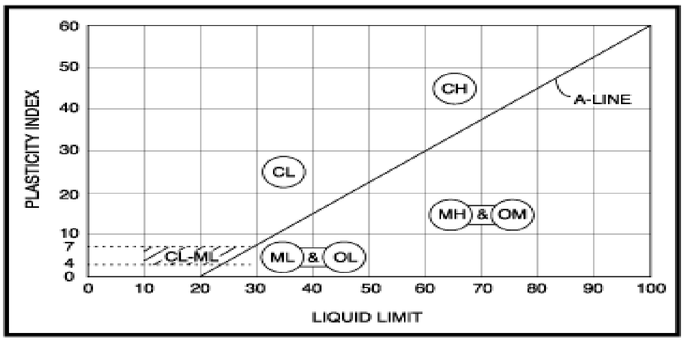


Figure 1: Cansagrande chart (Emesiobi, 2000)

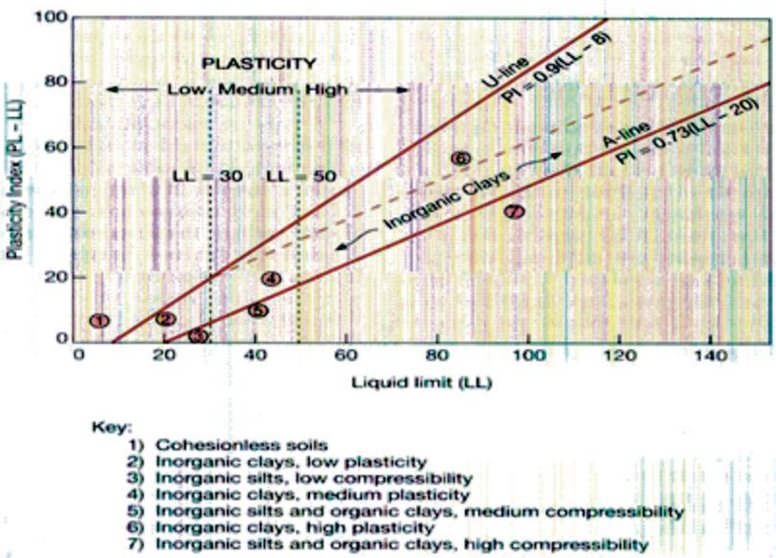


Figure 2: Plasticity chart (Emesiobi, 2000)

Clay has direct effect on the filters' strength, porosity and probability of cracking (Miller, 2010). The properties are parts of the essential filters' properties. The Ceramic Manufacturing Working Group, CMWG (2010) also stated that one of the important measures of clay quality identified is its plasticity, the ability to be shaped and moulded, which is directly related to its particle distribution and water content. It is therefore very necessary to consider the clay samples, being major material for filter production, based on their properties. Through analysis of the properties of the studied clay samples (see **Tables 1, 2 and 4**), it was revealed that the clay samples fall into Alumino-silicate group and the clays' properties were comparable with that of earlier clays used for CWF production. Alumino-silicate clay had earlier been used for ceramic filters production in Uganda (Kabagambe, 2010) and as shown in **Table 4**. The clays' plasticity (which is paramount factors for physical filtration ability of clay), and geographical locations of the clay samples were considered in their choice.

The basic properties required for effective performance of ceramic filters include linear shrinkage, strength, porosity, permeability, and water absorption. These properties were determined and presented in **Table 4**. However, some of the properties of filters produced with white (Birni Gwari) clay could not be determined due to warpage after firing and low plasticity of the clay-additive mixes.

3.2 Performance Assessments of the filters / Ceramic Water Filter Efficacy Tests

The efficiency of the filters produced from Nigerian clays to remove pollutants, such as suspended particles, dissolved particles and pathogens, from water were considered to determine their suitability. The performance assessments of the filters were based on flow rate, turbidity reduction in water, removal of total dissolved solids and total *coliform*. Earlier Researchers (Miller, 2010; Dies, 2003; Watter, 2010) had determined the filter performance by measuring the flow rate of water through a saturated filter, the removal of turbidity and removal of *coliform* bacteria, without colloidal silver application. The levels of performances in producing acceptable drinking water from ceramic water filters made from Nigeria clays were tested and results presented in **Figures 3 – 6**.

The choice of the most effective filter is based on higher flow rate (percolation) and acceptable turbidity, total dissolved solid and total *coliform* level in the filtrate. Low porosity/permeability militates against flow rate.

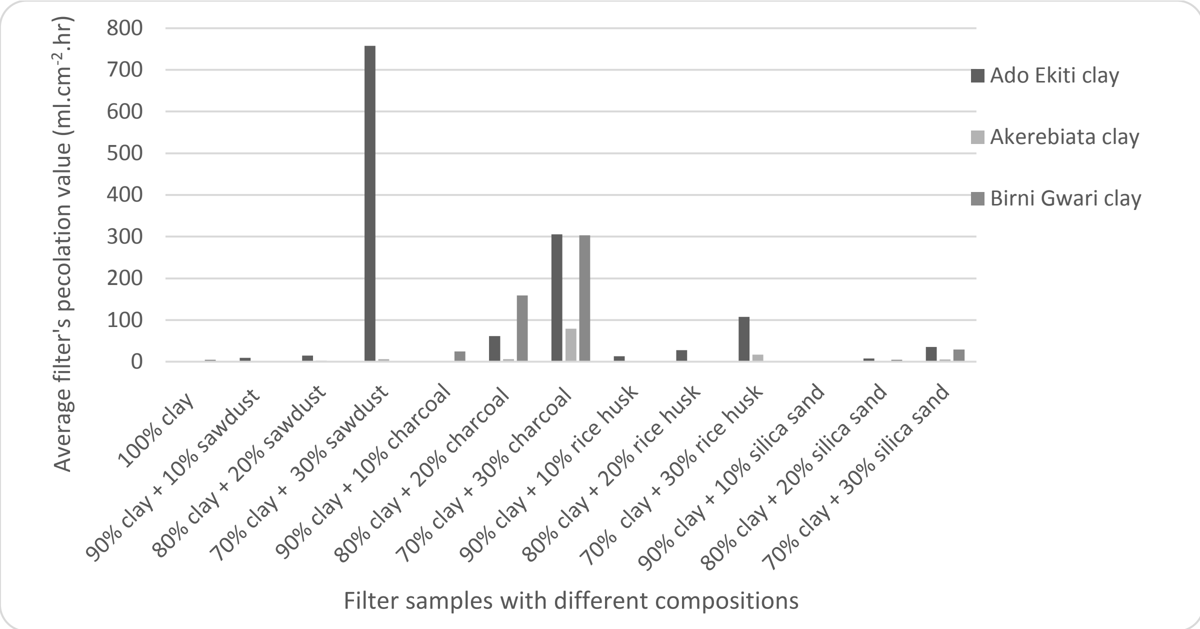


Figure 3: **Average percolation (flow rates per unit area) rate of water for the ceramic water filters produced from selected Nigerian clay deposits**

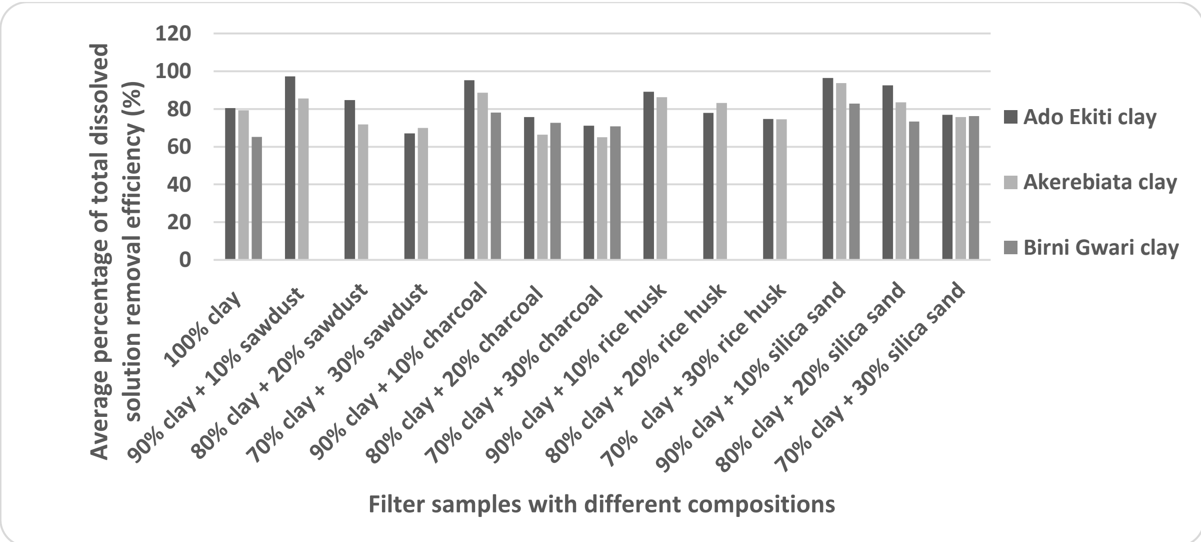


Figure 4: **Average percentage of turbidity removal efficiency of the ceramic water filters produced from selected Nigerian clay deposits**

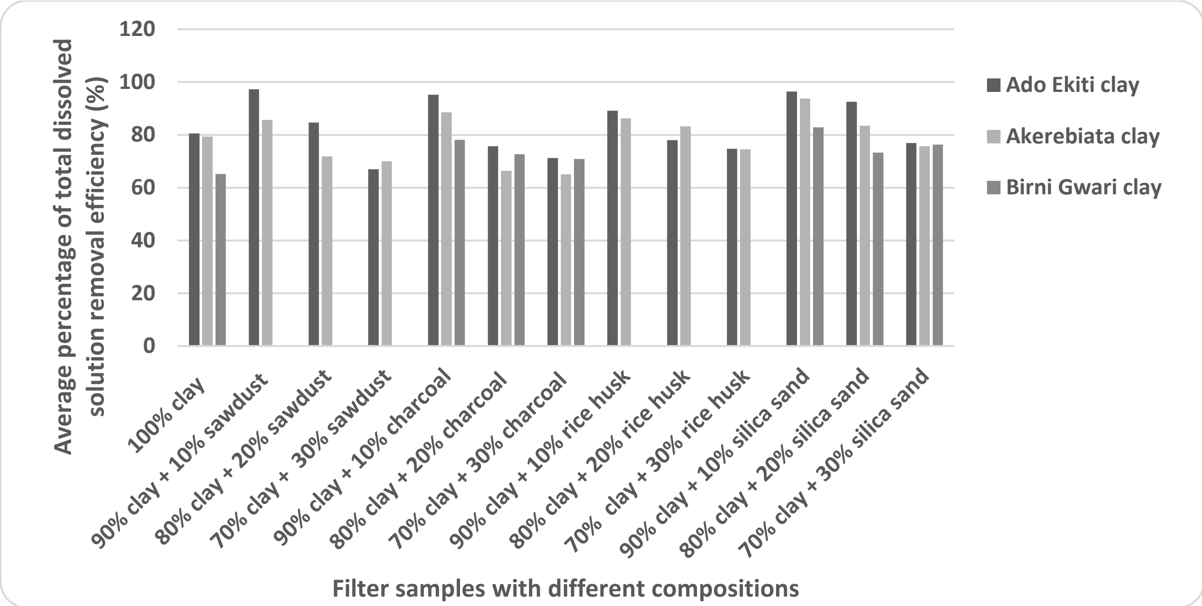


Figure 5: Average percentage of total dissolved solution removal efficiency of the ceramic water filters produced from selected Nigerian clay deposits

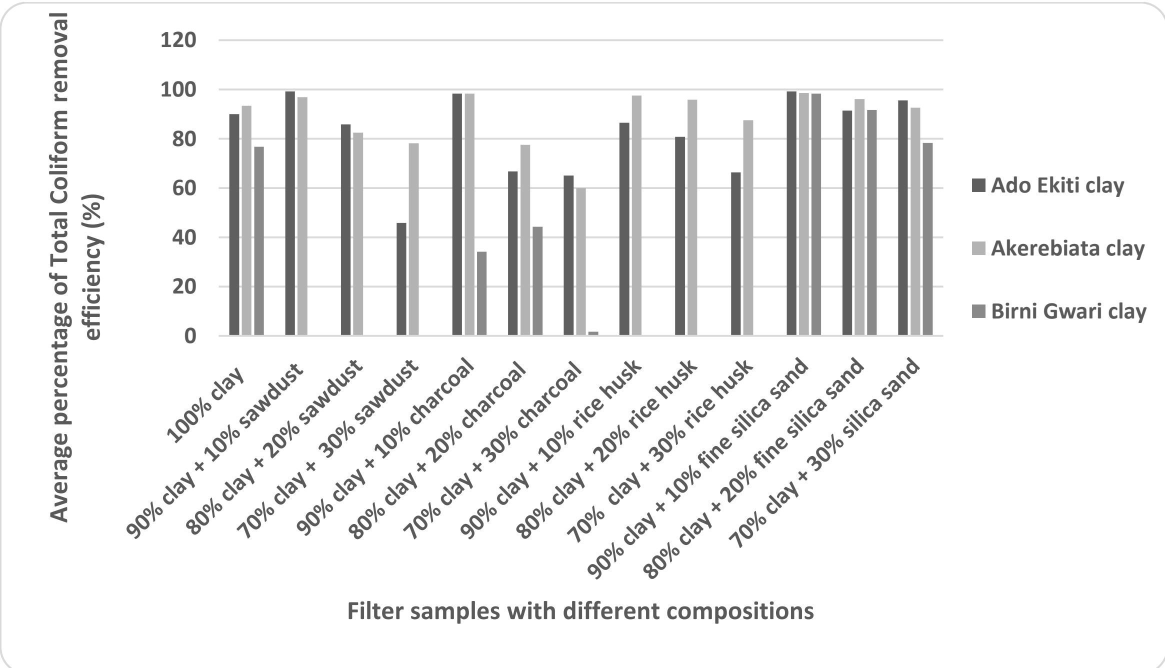


Figure 6: Average percentage of Total *Coliform* removal efficiency of the ceramic water filters produced from selected Nigerian clay deposits

Flow rate is a quality control measure used in almost every ceramic filter factory in the world. The tests results showed that the flow rates of the filters were in descending order of white (Birni Gwari) clay, red (Ado Ekiti) clay and black/ash (Akerebiata) clay. Low flow rates recorded in Akerebiata clay filter and Ado Ekiti (red) clay filter compared to that of Birni Gwari (white) clay filter were due to their higher plasticity, which results to their lower porosity, since the particles of the clay have the ability to be well compacted than that of Birni Gwari clay. Akerebiata clay filter, Ado Ekiti clay filter and Birni Gwari clay filter have plasticity of 52.6 %, 48.6 % and 34.2 % respectively. Birni Gwari clay was more porous (0.5 %) than Ado Ekiti clay (4.1 %) and Akerebiata clay (0.2439 %).

The flow rate in Ado Ekiti (red) clay filter was also in ascending order of 10 % sawdust (2.24 $ml.hr^{-1}$), 10 % charcoal and 10 % silica sand (25.0 $ml.hr^{-1}$), 20 % silica sand (200.0 $ml.hr^{-1}$), 10 % rice husk (310.34 $ml.hr^{-1}$), 20 % sawdust (324.8 $ml.hr^{-1}$), 20 % rice husk (689.66 $ml.hr^{-1}$), 30 % silica sand (844.44 $ml.hr^{-1}$), 30 % rice husk (2470.6 $ml.hr^{-1}$), 30 % charcoal (7,000 $ml.hr^{-1}$) and lastly 30 % sawdust (10,000 $ml.hr^{-1}$). The higher flow rate values of filters with 30 % sawdust and 30 % charcoal was a reflection of cracks (warpage) on their surfaces.

In Akerebiata clay, filter with 30 % charcoal also recorded the highest flow rate (1750 $ml.hr^{-1}$), while the filter with 10 % silica sand has flow rate of 0.15 $ml.hr^{-1}$ to be the least in the group. Also, in Birni Gwari clay filters, filter with 30 % charcoal was also identified with the highest value of 10,000 $ml.hr^{-1}$ flow rate, while filter with 10 % silica sand recorded lowest flow rate of 33.33 $ml.hr^{-1}$.

The water need of individual varies. The Best Practices Manual (CMWG, 2010) recommended 1.0 litre per hour as the minimum flow rate for filters. Though, Resources Development International Cambodia (RDIC) recommended 3.7 litres of water per day for human males older than 18 years, and 2.7 litres per day for female other than 18 years (Mayo -Clinic, 2004). The Institute of Health also determined that an adequate water intake for man was roughly 3.0 litres, while that of women was 2.2 litres of total beverages per day (United States Protection Agency, 2014). The British Dietetic Association recommended 1.8 litres per day as average human water intake. According to the United States Environmental Protection Agency (2014), average American adult water ingests was 2.0 litres per day. On an average, a man consumes about 2.0 litres of water every day (Jain and Rao, 2011). With critical consideration to the above daily human water intake, the studied filters will conveniently meet an average person daily water needs. Meanwhile in literature, people quote flow rates as one of the means to access filter performance without recourse to their limitation, non-consideration of variation in surface areas of filters (Kabagambe, 2010; Ankur and Wirat, 2014; Brown and Sobsey, 2007). In this study percolation will be preferred.

The percolation values of the clay samples were in descending order of white (Birni Gwari) clay (4.73 $ml.\ cm^{-2}.hr$), black/ash (Akerebiata) clay (0.17 $ml.\ cm^{-2}.hr$) and red (Ado Ekiti) clay (0.68 $ml.\ cm^{-2}.hr$) in line with the pattern of flow rates discussed above and shown in **Figure 3.** In Ado Ekiti clay, the filter with 30 % sawdust had the highest percolation of 757.80 $ml.\ cm^{-2}.hr$, while the filters with 10 % charcoal had the least value of 1.05 $ml.\ cm^{-2}.hr$. In Akerebiata clay, filter with 30 % charcoal displayed the highest value of 79.19 $ml.\ cm^{-2}.hr$, while the filter with 10 % charcoal had the lowest value of 0.85 $ml.\ cm^{-2}.hr$. In Birni Gwari clay category, filter with 30 % charcoal had the highest value of 303.03 $ml.\ cm^{-2}.hr$, while the filter with 10 % charcoal had the lowest value of 25.0 $ml.\ cm^{-2}.hr$.

The turbidity removal efficiencies (capacities) of filters made with Ado Ekiti, Akerebiata and Birni Gwari clays were 60 - 99.7 %, 18.3 - 99.7 % and 7.8 - 99.1 % respectively. Low level of additives in the filters enhanced the filters' turbidity removal efficiencies. As earlier shown in **Figures 3 - 6** above, that the lower the filters' porosity, the lower flow rates, which eventually results to high turbidity removal efficiency in the filters. That is, the lower the level of the CWF porosity, the higher its ability to grip or remove pollutants, but the lower the quantity of water to be filtered. The red clay (Ado Ekiti) filter with 10 % sawdust had the highest value of 99.7 % turbidity removal efficiency, while red clay filter with 30 % sawdust had the lowest value of 60 % turbidity removal efficiency in the clay group. In the black clay (Akerebiata) group, filter with silica sand had the highest value of 99.7 % turbidity removal efficiency, while 30 % charcoal had the lowest value of 18.3 % turbidity removal efficiency. In the case of white clay (Birni Gwari) filters, 30 % charcoal had the lowest value of 7.8 % turbidity removal efficiency, while filter with 10 % silica sand had 99.1 % turbidity removal efficiency.

The range of allowable level of turbidity in drinking water according to the Standards Organisation of Nigeria, SON (2007) for drinking water quality and World Health Organisation (WHO) were between 1.0 and 5.0 NTU. Asrafuzzaman *et al*. (2011) classified drinking water using level of turbidity in the water as lower turbid (25 – 35 NTU), medium turbid (40 – 50 NTU) and highly turbid (90 – 1200 NTU). Comparing the turbidity level of the filtrates to WHO allowable turbidity level, 87 % (34 out of 39) of the studied filter met the SON and WHO standards for drinking water. All treated (filtered) water with the tested ceramic filters fall within lower turbid water classification as classified by Asrafuzzaman *et al.* (2011).

The total dissolved solid removal efficiency in the filters results also showed higher effectiveness of filters with low additive level than that with high additive levels. Filters with 10% additive level had more ability to remove TDS in water than with filters with 20 % additive level; and filters with 20 % additive level removed TDS in water better than filter with 30 % additive level. As earlier discussed above, the lower the filters' porosity, the lower the permeability and the flow rates of the filters, which eventually resulted to higher capacity of the filters to remove total dissolved solids in water. Through analysis, the results showed that 98% of the tested CWF were able to remove between 52.9 – 97.0 % TDS in water.

The highest percentage value of total dissolved solid removal recorded was 97.3 % from 10 % sawdust-red clay filter, while the least value was 65.2 % from 100 % white clay filter. All the filters have the ability to remove TDS in water above 60 %, and up to 97.3 %. Illinois Department of Health classified the level of total dissolved solids in water as: satisfactory (<500 $mg.l^{-1}$), less than desirable (500 – 1000 $mg.l^{-1}$), undesirable (1000 – 1500 $mg.l^{-1}$) and unsatisfactory (over 1500 $mg.l^{-1}$) (Illinois Department of Health, 2000). Majority of the studied ceramic filters made with the selected Nigerian clay samples produced filter water with desirable (satisfactory) level of total dissolved solid in water.

The filters' abilities to reduce *total coliform* in water also increased as the additive level decreased in the filters as reflected in **Figure 6**. This was in line with the trend of reducing other pollutants in the water as earlier discussed. The efficiency of the filters to reduce *coliform* in water was in ascending order of 30 % additive level, 20 % additive level and 10 % additive level. The results reflected correlation between porosity, flow rates and effectiveness of the filters to produce safe water, since flow rates of the filters increased with increased in the filters' porosity, which resulted to low effectiveness to remove pollutants.

Analysis from results showed that 74.5 % (38 out 51) of the filters reduced 80 - 99.2 % total *coliform* in water, 15.7 % (8 out of 51) of the filters reduced 60 - 79.9 % total *coliform* in water. Generally, 90.2 % of the filters reduced 60 – 99 % total *coliform* in the filtered water sample. The red clay filters have the total *coliform* removal efficiency ranging from 45.8 to 99.2 %. Filter with 10 % fine silica sand in the red clay had the highest value of 99.2 %, while filter with 20 % charcoal in red clay has the lowest value of 45.8 %. In case of filters made with black clay, all have values above 76 %, up to 98.3 %. White clay filters have low values generally, except for white clay filters with silica sand. This is attributed to cracks in the filters. Though, it is difficult to measure the presence of harmful pathogen, but an indirect measure of water quality use is the measurement of an indicator like *coliform* bacteria as a common practice. Daniel (2007) was of the view that clay can remove *coliform* but not 100 % removal. Brown and Sobsey (2006) also achieved 95.1 % up to 99.99 % *E.coli* reduction in drinking water with the use of various ceramic water filters. Sophie (2007) was also able to reduce total *coliform* in water with ceramic water filter in Nicaragua. Brown and Sobsey (2007) also attained 90 – 99 % reduction in viruses with the use of ceramic water filter to treat water. Some of the studied ceramic filters were able to reduce *coliform* in water up to 99 %.

On the average level, CWFs with 30% silica sand were most suitable, followed by CWFs with 20 % silica sand, considering the filters' strength, flow rate and efficiency to remove unwanted particles in the water. The filters from white clay were weak in terms of strength; this made the clay material less suitable for filter production, out of all three types of clay investigated. Following the trend of the results, if additive level was more than 30 %, the porosity and flow rate of the filter would be enhanced. This would adversely affect the filter's efficiency to remove unwanted particles in the water. This study calls for further study using additive level greater than 30% to actually determine the level when the filter's efficiency will be affected.

The results in **Figures 3-6** revealed that the suitability of the study clay samples for production of CWF is in descending order of Ado-Ekiti (red clay), Akerebiata clay (black/ash) clay and Birni-Gwari (white) clay.

In general, the lower the proportion of additive (charcoal/sawdust/rice husk/ silica sand) in the clay-additive mix (filter), the lower the filter's flow rate (percolation), and the higher the filter's efficiency to remove pollutants. Meanwhile, the need to meet the demands of the user(s) of the filter in term of quality and quantity of water is of high significance. Therefore, the choice of moderate proportion of additive in the clay-additive mix (filter) to produce quality and quantity of water that can meet the users' demands needs to be considered. From the analysis of results (as presented in **Figures 3-6**), 20-30 % additive level will be preferred to be the most suitable for formation of pores in the CWF to produce safe water of desired (satisfactorily) standard.

4.0 CONCLUSION

The following conclusions were drawn from the results as follows:

- Studied clay samples fell within silt-clays, high compressibility, high plasticity clays with low shrinkage value (1-15 %) in alumino-silicate group.
- The selected Nigerian clay samples with higher plasticity (Ado-Ekiti clay and Akerebiata clay) were found suitable for ceramic water filter production. Though, Ado-Ekiti clay was the most suitable type of clay for filter production.
- Considering the strength, moderate flow rate and high pollutants removal efficiencies, silica sand were found to be more suitable to create pores in Nigerian clay samples for ceramic water filter production than combustible materials (rice husk, sawdust and charcoal).
- Though, low level of additive in the clay enhances the filters' abilities to remove pollutants, but to meet the need of the users (in terms of quantity and quality of water), 20 – 30 % additive levels were preferred to be the most suitable for moderate formation of pores in the clay-additive mix (filter).
- Majority of the CWF made with the selected Nigerian clay samples produced drinkable water desirable (satisfactory) level of total dissolved solid.

- Nigerian clay filters were capable to remove turbidity, reduce total dissolved solid and total *coliform* in water up to 99.7 % without application of colloidal silver or any other chemical for pathogen removal.

RECOMMENDATION

Based on the findings of this study, this study recommends that the Information on the most suitable filter can be used to produce filter with larger size for individual or group use.

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