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HOUSEHOLD WATER TREATMENT USING CERAMIC FILTER FROM NATURAL CLAY AND SUGARCANE BAGASSE FOR POTABLE USE IN RURAL AREAS

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ABSTRACT
Nigeria did not meet the millennium development goal (MDG) target of 75% coverage of safe drinking water in 2015. This research is aimed at evaluating the suitability of ceramic water filter made from natural clay and sugarcane bagasse to remove turbidity and pathogens from surface water for household drinking purpose. Preliminary filters were constructed from different proportions of clayto sugarcane bagasse and 90% clay –10% sugarcane bagasse gave a good flowrate of 2.5 L/hr. Four filters were constructed and were labeled Filters A, B, C and D based on different methods of silver nitrate application. Raw water was collected at Riminguza Dam and100 filtration runs were conducted in all the four filters. pH, turbidity and total coliform (TC) count were tested before and after the 1st, 5th, 10th, 20th, 50th and 100thfiltration runs. The raw water result on pH, turbidity and TC countwas6.7, 46.3 NTU and 70 count/100 ml respectively. The result of 100 filtration runs on the four filters on pH ranged from 7.07 to 7.17, turbidity ranged from 2.69 to 3.76 NTU and the TC count ranged from 2 to 22 count/100ml.Filter C and D were found to be more effective in terms of coliform removal. The filtered water was found to conform to the WHO and Nigerian standards for safe drinking water quality.
Keywords: *Turbidity, pathogens, raw water, standards.*

INTRODUCTION
The quality of drinking water plays a major role in maintaining public health. Bacterial pathogens in water of poor quality tend to cause gastrointestinal infections such as diarrhea, dysentery, typhoid, shigellosis and human enteritis. One of the most common cause of illness and deaths in the developing world is cholera, which is caused by a bacterial pathogen classified as Vibrio cholerea (Jocelyne, 2012).Water can be contaminated both chemically and microbiologically. Of primary concern in efforts to reduce mortality and morbidity caused by infectious disease is the microbiological quality of water. Pathogens transmitted through contaminated drinking water include pathogenic bacteria, viruses, protozoa and helminths. Although diarrheal disease is usually transmitted through drinking water, it can also be transmitted via faecal-oral routes. Transmission pathways include consumption of contaminated food or drinks, poor sanitation and poor personal hygiene. It was in recognition of the importance of water quality for drinking that United Nation declared a decade for drinking water supply from 1981-1990 and urged governments and NGOs to set up realistic standards for both urban and rural settlement. This was followed by the setting up of the millennium development goals which seeks to provide among other things portable and quality drinking water to half of the world population by the year 2015 and up to now it has not been realized.

Ceramic pot filtration is a common form of household water treatment in many parts of the world. Several studies have reported that the clay used in pottery production is also suitable for making ceramic water filters (Hagan *et al*., 2009, Oyanedel-Craver and Smith, 2008. and Rivera, 2006). Rice husk sawdust, coffee husk, and peanut husk have been used as combustible materials to the ceramic pot filter which create porous spaces that allow water to pass through. Flow rate testing is an important quality assurance step which indicates the rate at which water passes through the filter. The acceptable flow rate range of ceramic filter should be within 1.0-3.5L/hr (Hagan *et al.,* 2009). Silver is added to improve the effectiveness of the filter as a disinfectant. Colloidal silver, a suspension of silver Nanoparticles, is either added to the filter mix, coated to the filter after firing, or the filter is dipped into the colloidal silver solution (Rayner, 2009). Silver nitrate is applied to filters instead of colloidal silver at some factories (Rayner, 2009). Several studies have shown that silver Nanoparticles have strong antibacterial properties and could be used in biomedical and environmental applications, such as for the treatment of wounds and burns (Furno *et al.,* 2004) and for water disinfection (Jain and Pradeep, 2005). Silver is applied to the filter for two reasons: to take advantage of the bactericidal quality of silver in the purification of water as it is filtered; and to prevent the growth of a slime layer of bacteria that can form on the filter wall. Home-made ceramic filters have many potential advantages as a point-of-use water treatment technology. They can be manufactured with mostly local materials and cheap labour. It is a socially acceptable technology that can work year round in different climates because clay pots are often used as storage container for water. It does not impart an objectionable taste to the treated water. It is designed to remove both turbidity and pathogens (The Ceramics Manufacturing Working Group, 2011).

Many studies assessing the performance of ceramic water filters have found them to be highly effective in removing total and faecal coliforms from bacterially contaminated water sources (Clasen *et al.,* 2007). Under laboratory conditions the ceramic water filter technology should remove 99.8% of the TC and E. coli (PEP, 2007). Some other studies revealed that the effectiveness of ceramic water filters at removing bacteria, viruses, and protozoa depends on the production quality of the ceramic filter. Most ceramic water filters are effective at removing most of the larger protozoan and bacterial organisms, but not at removing the smaller viral organisms (CDC, 2008). Studies have also shown that pathogenic bacteria are removed from contaminated water sources by filtering the water through high quality locally produced ceramic water filters, especially in developing countries (Clasen *et al*., 2007). This research work intends to produce a locally made ceramic filter made from natural clay and sugarcane bagasse for household water treatment. The objectives of this research are:

(1) To determine the effectiveness of sugarcane bagasse as a burnout material

(2) To determine the most effective method of silver nitrate application

(3) To determine the turbidity and TC removal efficiencies and the corresponding flow rate reduction from the filter

(4) To compare the filtrate water quality with WHO and Nigerian standards for drinking water quality

MATERIALS AND METHODS

Production Process

The production process of ceramic filter involves two stages: preliminary production and final production stages. In the preliminary production, the proportion of clay to sugarcane bagasse and water was varied until the right plasticity was achieved in the mixture and the appropriate filtration rate in the fired element reached. The proportion of clay to sugarcane bagasse that gave the filtration rates of 1 to 3.5 L/hr was chosen to construct four filters at the final production stage.

Preliminary Filter Construction

Equipment and materials

1) Clay (pounded and sieved)
2) Plastic buckets and water
3) Sugarcane bagasse (hammer milled and sieved)
4) Scale (Camry dial spring scale, capacity: 20 kg)
5) Potter's wheel obtained at the Pottery Department Katsina Youth Craft Village.

Preparation of Raw Materials

Sifting the clay and sugarcane bagasse is important to ensure that the voids in the ceramic filter are of the correct size. Voids that are too big will cause faster flow rate and lesser turbidity removal while voids that are too small will give effective turbidity and pathogens removal but slower flow rate to produce enough drinking water.

(1) Natural soil was obtained from a pit located in Kankia Town. The soil was analyzed for index properties. The soil was crumbled and sifted using a window frame (1m square with net of aperture size 0.425 mm). The soil was dumped onto the sieve and then shaken onto a clean floor. The sifted material was then swept up with broom and dustpan and placed into a container for mixing.

(2) Raw sugarcane bagasse was obtained at Dandume Town local sugar factory. T he raw sugarcane bagasse was grinded using Simba hammer milling machine at Katsina Central Market, it was sifted (using a window frame with net of aperture size 0.425 mm) and stored in grain sacks.

(3) Clean water (measured in litres) was used in mixing the clay and the sugarcane bagasse.

Mixing filter recipe

The proportions of the clay to the sugarcane bagasse are crucial in determining the right 'plasticity" and final flow rate of the filter. A 50:50 mix by volume of clay to bagasse material is a good place to start. More clay was added to the mixture if it is not very plastic (e.g. a 60:40 mix of clay to bagasse). A total weight of 5 kg was chosen to be the total weight of one unit of the filter and Table 1 shows the recipe for the filter construction.

Table 1: Recipe for construction of a preliminary ceramic filter

Clay (kg)	2.5	3.0	3.5	4.0	4.5
Clay (%)	50	60	70	80	90
Sugarcane bagasse (kg)	2.5	2.0	1.5	1.0	0.5
Sugarcane bagasse (%)	50	40	30	20	10
Water (L)	1.5	1.5	1.5	1.5	1.5

For the recipe, the respective mass of the clay and the sugarcane bagasse were measured for each proportion and were kept separately in a plastic container. The dry-mix of the materials for each proportion was mixed by hand for five minutes until the entire mixture feels homogeneous. After the dry ingredients have been mixed thoroughly, 1L of water was added with continuous mixing by hand. The water was increased to 1.5L in all the mixtures and it was observed that only proportion of 90% clay to 10% sugarcane bagasse became cohesive. This proportion was further altered by slightly increasing and decreasing this ratio as shown in Table 2.

Table 2: Proportions of sugarcane bagasse to clay

Clay	4.2	4.	4.	4.	4.	4.	4.	4.	5.0
Clay (%)	85	86	88	90	92	94	96	98	10
Sugarca	0.7	0.	0.	0.	0.	0.	0.	0.	0.0
Sugarca	15	14	12	10	8	6	4	2	0
Water	1.5	1.	1.	1.	1.	1.	1.	1.	1.5

Forming of Clay Cubes into Ceramic Filter Form using Potter's Wheel

The clay and sugarcane bagasse mixtures were wedged separately by kneading each mixture aggressively in a rocking motion; this process was carried out continually until the mix appeared uniform. This step is also important to remove any air pockets within the clay. The clay was formed into an approximate cube and the top and bottom sides were slapped with flat hand to create smooth surfaces. This process was repeated for all the wedged proportions. The potter's wheel used in this research is called kick wheel and the cubes were formed into the ceramic filter form. All the filter elements were surfaced using the potter's wheel and were labeled according to their proportions.

Drying and firing the filter

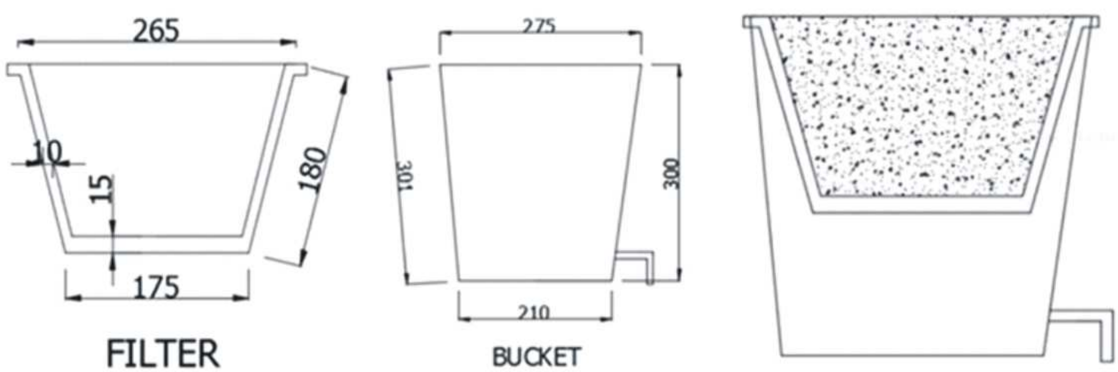
The purpose of drying the filter is to remove as much moisture as possible before putting it into the kiln. The filters were left for 8 days to dry completely at room temperature before firing. If the pot has excessive moisture, the water will evaporate and will cause the pot to crack, so the filters were air dried to avoid cracking. The dried ceramic filters were carefully loaded into the kiln and stacked in a formation that will maintain uniform heat distribution. Small pieces of fired clay were used to separate the filters in the kiln. The kiln door was sealed partially with bricks and mortar. An industrial thermometer probe was placed in one of the mortar joints in order to monitor the temperature inside the kiln. The fire woods were set ablaze. The temperature was allowed to reach 100^oC . At this point, the water moisture inside the pot will get chance to escape before it boils at 100^oC and this temperature was maintained for 2 hours. Any temperature above this may cause excess water to expand quickly and crack the filters. After 2 hours, the temperature was increased gradually by adding more fire wood until the temperature reached 890^oC and it was held for 3 to 4 hours.The clay filters have now become ceramics and were left overnight to cool inside the kiln. The mortar and bricks were carefully removed and stacked away the following day and also the ceramic filters were removed carefully.

Flow-Rate Testing of Ceramic Filters

Flow rate of the filter was measured by filling up the filter to the rim. The flowrate measured is the maximum initial flow rate, because the flow rate is decreasing with declining head. Each filter was soaked in bucket full of clean water for 24 hours, so that the pores will be completely saturated by the water. After 24 hours, the ceramic filters were removed from the buckets and were thoroughly checked to ensure that there were no cracks. Each filter was filled with clean water and after one hour the rate of filtration was measured.

Final Filter Construction

After the flow rate test, the proportion of 90% clay–10% sugarcane bagasse with flowrate of 2.5 L/hr was chosen to construct the final filters. Four filters namely: Filter A, Filter B, Filter C and Filter D were constructed. All the filters were constructed using the same procedure in the preliminary filter construction except Filter B in which dilute silver nitrate solution was used when mixing the clay and the sugarcane bagasse at initial stage instead of clean water. Figure 1 shows the filter configuration indicating the ceramic filter, the plastic receptacle for filtrate collection and the filter system while Plate 1 and 2 show pictures of the filter before and after drying.



(a) Filter (b) Bucket (c) Filter and receiver

Figure 1: Filter design configuration

Plate 1: Four filters before drying

Plate 2: Four filters after drying

Silver application

The silver solution used was silver nitrate $AgNO_3$ ($3.2\ \%\ concentration$).Filter A was not treated with silver nitrate. For Filter B;10 ml of $AgNO_3$ was added to 1.5L of clean water to make a solution. The solution was used in mixing the clay and the sugarcane bagasse at initial stage before firing. For Filter C;100 ml of $AgNO_3$ was added to 15L of clean water to make the silver nitrate solution and the filterwas dipped in to the solution for 45seconds. For Filter D;2ml of $AgNO_3$was added to 300ml of clean water to make the solution and 200ml was painted inside and 100ml was painted outside. The ceramic filters were left to dry off completely before use (Rayner, 2009; Oyanedel-Craver and Smith, 2008 and Lantagne, 2001a and b).

Packaging of filter system

Plastic containers were prepared by punching a hole in the side near the bottom and were fitted with a plastic faucet (tap) for dispensing filtered water. Plate 3 shows the 4 filters with plastic receivers for collecting the filtered water.

Plate 3: Four filters with plastic receivers

Ceramic filter efficiency tests

Raw water sample was collected at RiminGuza Earth Dam located at Karare Village, Rimi L.G.A of Katsina State. Five litres of the raw water were poured in each of the respective filters (i.e. Filter A, Filter B, Filter C and Filter D). The filtrate from each filter was collected in a small rubber container. The parameters tested were pH, turbidity and TC count. In order to test the efficiency of the filters with usage, one hundred (100) filtration runs were conducted in all the four filters. The filtrate of the 1st, 5th, 10th, 20th, 50th and 100th filtration runs were collected and taken to Ajiwa Water Treatment Plant Laboratory for turbidity and TC test. Similarly, flow rate test was conducted in all the four filters at the interval of the 1st, 5th, 10th, 20th, 50th and 100th filtration runs. The filters were filled with the raw water and after one hour the filtrate samples were collected and measured in litres. Therefore the remaining water was left to flow out completely and the filters were filled again with the raw water.

RESULTS AND DISCUSSION

Preliminary Tests

Soil properties

Preliminary tests on index properties of the soil indicated the following: Liquid limit of 32%, Plastic limit of 22.6%, Plasticity index of 9.4%, Linear shrinkage of 21% and Specific gravity of 2.42. Grain size analysis of the soil gave the following result: D_{10} of 0.1 mm, D_{30} of 0.17 mm and D_{60} of 0.25 mm.

Filter recipe mixture and flowrate

The various proportions of clay (C) to sugarcane bagasse (SB) and the corresponding flow rates of the preliminary filters constructed are shown in Table 3. This stage is crucial in order to determine the plasticity and final flow rate of the filters. The right plasticity was achieved at 86C:14SB mix by percentage up to 100C:0SB with 1.5 L of water added because samples were cohesive enough to be wedged when 1.5 L of water was added. After firing, the flow rate of each filter was obtained and 90C:10SB (%) with flow rate of 2.5 L/hr was chosen to construct the final four filters.

Table 3: Preliminary filter construction flow rate

Clay to Sugarcane Bagasse *(kg)*	Clay to Sugarcane Bagasse *(%)*	Water Added *(L)*	Flow rate *(L/hr)*
5.0C:0.0SB	100C:0SB	1.5	0.00
5.0C:0.0SB	100C:0SB	1.5	0.00
4.9C:0.1SB	98C:2SB	1.5	0.30
4.8C:0.2SB	96C:4SB	1.5	0.80
4.7C:0.3SB	94C:6SB	1.5	1.30
4.6C:0.4SB	92C:8SB	1.5	1.80
4.5C:0.5SB	90C:10SB	1.5	2.50
4.4C:0.6SB	88C:12SB	1.5	3.30
4.3C:0.7SB	86C:14SB	1.5	3.70

NB: Total weight of both clay and sugarcane bagasse used was 5 kg.

Filter Efficiency

Turbidity removal efficiency

Figure 2 shows the trend in turbidity removal after the 100th filtration runs in the four filters. The raw water sample had a turbidity of 43.6 NTU. Filter A water sample had a turbidity of 3.92 NTU with removal efficiency of 91.0% from the 1stfiltration run and at the 100th filtration run it reduced to 3.39 NTU with removal efficiency of 92.2%. Filter B sample had a turbidity of 2.83 NTU with removal efficiency of 93.5% from the 1st filtration run which decreased to 2.35 NTU at the 100th filtration run with removal efficiency of 94.6%. Filter C sample had a turbidity of 3.27 NTU with removal efficiency of 92.5% from the 1st filtration run and at the 100th filtration runs it had a turbidity of 2.78 NTU with removal efficiency of 93.6%. Filter D water sample has a turbidity of 3.10 NTU with removal efficiency of 92.9% from the 1st filtration run and at the 100th filtration run it has a turbidity of 2.63 NTU with removal efficiency of 94.0% respectively. Bloem *et al.* (2009) indicated that the water turbidity affects the filter flow rate and the higher the turbidity of the raw water, the lesser the life span of the ceramic filter. Generally, there is an improvement in turbidity removal efficiencies with number of filtration runs in all the four filters. The turbidity removal efficiencies were in the order: Filter B > Filter D > Filter C > Filter A.

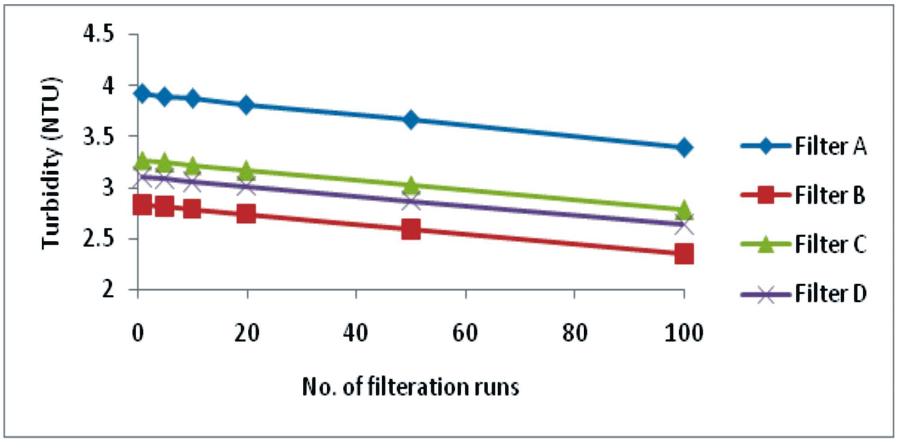


Figure 2: Trend in turbidity of filtered water over 100 filtration runs

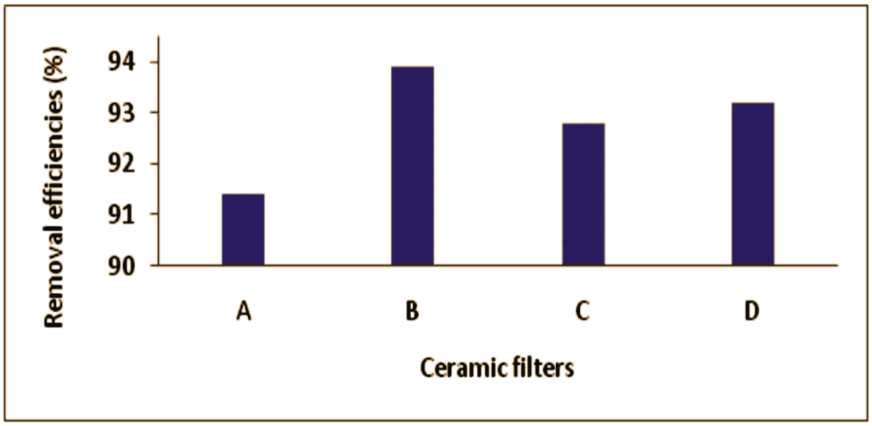


Figure 3: Average turbidity removal efficiencies

The average turbidity removal efficiency of all the four filters over 100 filtration runs is presented in Figure 3. Filter A had 91.4%, Filter B had 93.9%, Filter C had 92.8% and Filter D had 93.2%. All the four ceramic filters are capable of reducing the turbidity of water samples to the value below the WHO and Nigerian standards for drinking water quality of less than 5 NTU. It is expected that high turbidity in water might cause higher concentration of pathogens and a higher possibility of transmitting waterborne diseases.

Total coliform (TC) removal efficiency

The performance of the filters with respect to TC removal is as presented in Figure 4. The TC of the raw water sample was 70 count/100 ml. Filter A had 75.7% TC removal efficiency from the 1stfiltration run and at the 100th run it reduced to 68.6%. Filter B achieved 81.4% TC removal efficiency from the 1st filtration run and 80.0% TC removal efficiency at the 100th filtration run. Filter C had 97.3% TC removal efficiency from the 1st filtration run and at the100th filtration run it was 97.1% while Filter D achieved 97.1% and 91.4% TC removal efficiency from the 1st filtration run and the 100th filtration runs respectively. Generally, there was a slight decrease in TC removal with the number of filtration runs in all the filters. The TC removals from the filters were in the order: Filter C > Filter D > Filter B > Filter A.

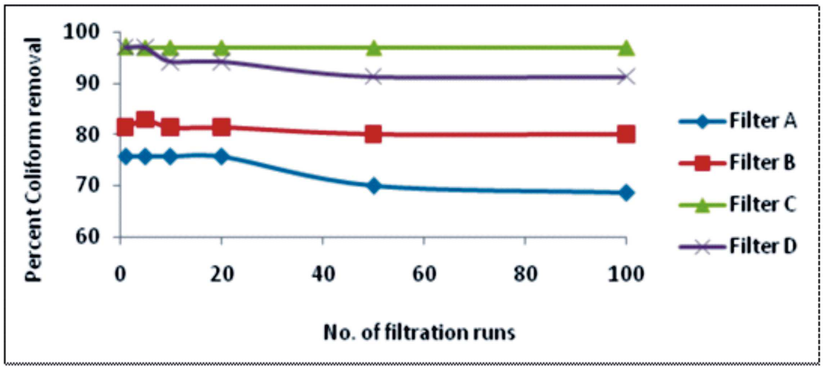


Figure 4: Trend in percent TC removal in filtered water over 100 filtration runs

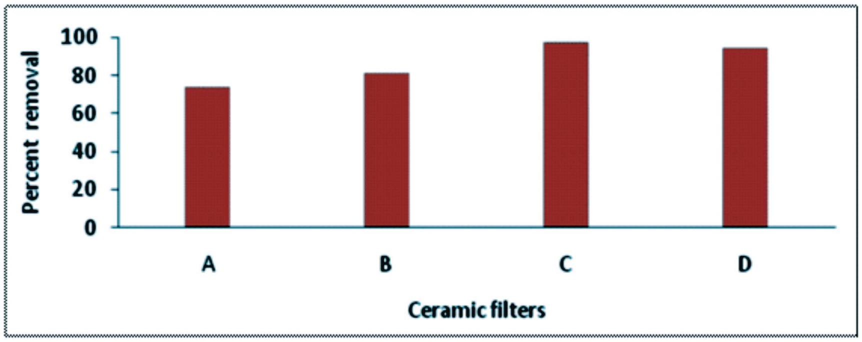


Figure 5: Average TC count removal efficiency

Figure 5 shows the average coliform removal efficiencies of the four filters. Results show that Filter C and D are capable of removing more than 90% of the TC bacteria below the maximum permissible level of 10 cfu/100 ml set by Nigerian standard for drinking water quality. It would be recalled that Filter C was dipped into silver nitrate solution while Filter D was painted with the silver nitrate solution.

Flow rate changes with filtration runs

Figure 6 shows the trend of flow rate reduction in the filters at filtration runs of 1st, 5th, 10th, 20th, 50th and 100th. Filter A with initial flow rate of 2.0 L/hr had its flow reduced to 1.2 L/hr at the 100thfiltration run corresponding to 40% reduction in flow rate. The flow rate in Filter B reduced from 1.9 L/hr at the 1st filtration run to 0.8 L/hr over 100th filtration run and this corresponds to 57.9% reduction in flow rate. Filter C had a flow rate of 2.1L/hr at the 1st filtration run and 1.1 L/hr at the 100th filtration run representing 47.6% reduction in flow rate. In Filter D, the flow rate of 2.4 L/hr at the 1st filtration run reduced to 1.3 L/hr at the 100thfiltration run corresponding to 45.8% reduction in flow rate. The reduction in flow rate of all the filters is as a result of clogging of the cera mic pores due to suspended particles in the raw water sample. When the filtration rate becomes low enough such that the filter can no longer provides enough drinking water, the filter losses its effectiveness. Lantagne (2001a) reported that filtration rates decreased markedly over time especially in turbid waters.

Apart from the presence of suspended solids, another parameter that affects the filter flow rate is the ratio of the sugarcane bagasse to clay. If the volume ratio of the bagasse is increased, more pores are created in the filter and water flows through the filter at faster rate. Water containing high organic content or suspended particles slow down the flow rates of water by progressively clogging the ceramic pores and this affects the quality of the filtered water collected.

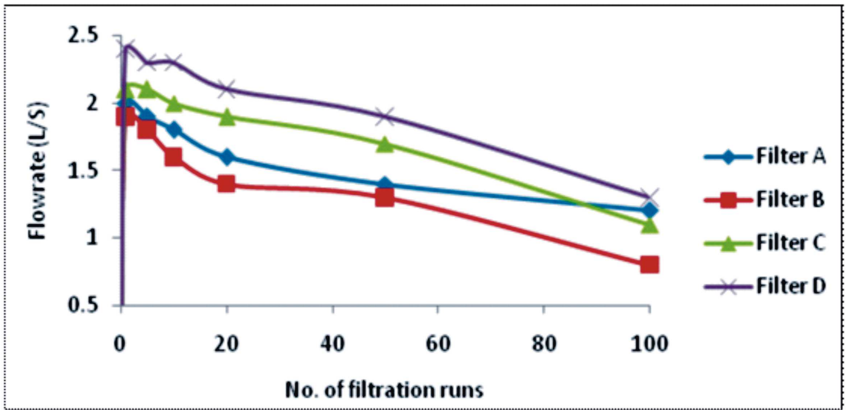


Figure 6: Trend of flow rate reduction from the filters over 100 filtration runs

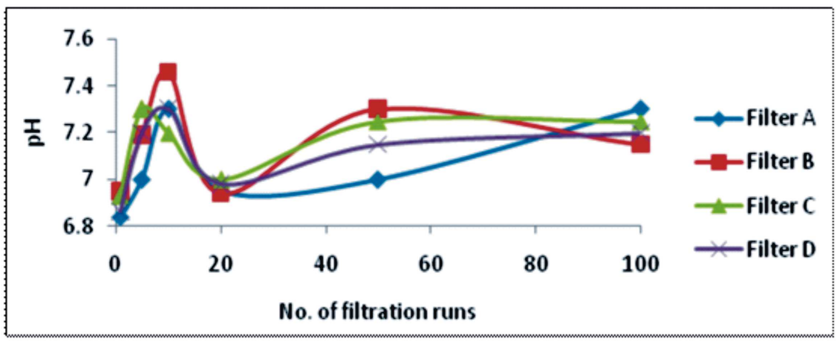


Figure 7: pH changes over 100 filtration runs

pH changes with filtration runs

Figure 7 shows the result of the pH changes that occurred in the filtrate samples in the four filters after the one hundredth filtration run. The pH of the raw water before filtration was 6.7. The pH appears to fluctuate with filtration runs, but generally, there is an increase in pH after the filtration in all the four filters and the increase in the pH could be due to the combination of clay and silver nitrate. The results of pH in all the four filters are within the range given by WHO and Nigerian standard for drinking water quality of 6.5-8.5.

CONCLUSIONS

The need for safe drinking water necessitates new approaches that can offer immediate solutions in the rural areas with no safe drinking water. In this research, four filters were made from locally sourced materials and the filters were tested to evaluate their performance. The filter system comprises of the filter element and plastic receptacle. The turbidity of the raw water sample was 43.6NTU and the average post filtration turbidity removals of Filters A, B, C and D were 91.4%, 93.9%, 92.8% and 93.2% respectively. The results on the turbidity from the four filters were within the range given by WHO and Nigerian standard for drinking water. The average TC removal efficiency of Filter A, B, C and D were 73.6%, 81.2%, 97.1% and 94.3% respectively. This shows that filter C and D were able to remove the coliform bacteria to acceptable Nigerian standard for drinking water quality with Filter C giving the best result. The percentage flow rate reduction indicates that Filters A, B, C and D gave 40%, 57.9%, 47.6% and 45.8% reductions respectively. The result of pH shows a slight increase in the pH, but all the pH were within acceptable WHO and Nigerian standard limits for drinking water quality. Regular scrubbing of the ceramic filter is recommended in order to prevent clogging and to rejuvenate the filtration rate.

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