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Development of Ceramic Filters for Household Water Treatment in Nigeria

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Ceramic water filtration is the process that makes use of a porous ceramic (fired clay) medium to filter microbes or other contaminants from water. Ceramic water filtration has been greatly improved upon such that it takes care of most microbial contamination in water. However, the ceramic filter is not known to treat chemical contaminants in water. Therefore this project was aimed at developing a ceramic filter that could treat certain chemical contamination in water at the household level. Porous ceramic bodies were formulated and constituted from various materials such as kaolin, laterite, bonechar and charcoal. Bone char was added as a defluoridation agent while the charcoal doubled as the pore-creating combustible material and as an Activated Carbon media in the ceramic body for the adsorption of metals from water. The formulated ceramic bodies were shaped into filters (pot) using the slip casting technique and fired bisque (850˚C - 900˚C). The developed filter samples were subjected to physical properties tests, while analysis on the microbial and physio-chemical parameters of the filter-treated water samples were compared vis-à-vis the raw water samples. The results indicate that the developed filters were effective in the treatment of chemical contaminants detected in the raw water samples; with significant reductions in fluoride, lead, and sulphate levels amongst others. The resulting filter samples also showed viability in physical handling strength and flow rate; while the availability of the raw materials and the processing technique used, makes a good economic case for the production of the developed filters.

Keywords: Ceramic Water Filters; Bone Char; Activated Carbon; Contaminants

Introduction

A filter is defined as a device, instrument or material, which removes something from whatever passes through it. Therefore, ceramic water filtration as defined by Brown, Sobsey and Proum (2007), is the process that makes use of a porous ceramic (fired clay) medium to filter microbes or other contaminants from water. The pore size of the ceramic medium is sometimes small enough to trap anything bigger than a water molecule. From the ancient times to the present, water filters have evolved out of necessity, first to remove materials that affect appearance, then to improve bad tastes and further to remove contaminants that can cause disease and illness (The Water Exchange, 2012). From the boiling of water to improve taste and then filtering through a cloth bag, to the ceramic cartridge for removing bacteria from water and the ceramic pot filter developed by Dr. Fernando Mazariegos of the Central American Industrial Research Institute (ICAITI) in Guatemala, to make bacterially contaminated water safe for drinking. Ceramic filters were popularly used for centralized water treatment but in recent times they are being manufactured for point of use applications (National Academy of Sciences, 2008). And the World Health Organisation (WHO) encourages its use as household water treatment systems (HWTS) for effective treatment of drinking water. These porous ceramic water filters which vary widely in design, effectiveness and cost, are now treated with a silver solution which acts as a microbicide to inactivate bacteria and this has contributed to the increased performance of ceramic water filters. However, the ceramic filters have been shown to be limited and incapable of treating viral and chemical contamination in water.

While diarrhoea is considered the most predominant water borne disease, infectious diseases caused by pathogenic bacteria, viruses, protozoa and fungi are regarded the most common and widespread health risk associated with drinking water (WHO, 2011). Chemical contamination of drinking water sources is also an issue of concern as millions of people are exposed to unsafe levels of chemical contaminants in their drinking water (WHO, 2011) and long term exposure to chemical pollutants can have serious health implications.

In Nigeria, virtually all urban areas suffer water supply shortages relative to demand and infrastructural failure. The public water supply is erratic, intermittently unreliable, and, in some cases, inaccessible, thus resulting in high dependency on supplementary sources such as boreholes, wells, brooks, rain, springs and streams (Aribigbola, 2010). This poor access to safe water has a lot of implications for sustainable development. And while, shallow wells are the most common sources of water in Akure, they are often of poor microbial and aesthetic quality and hence not suitable for drinking (Okoye & Adeleke, 1991). Other groundwater sources like deep wells and boreholes can be sparsely found, but are also not suitable for drinking because they can contain naturally occurring mineral and chemical contaminants from underlying rocks. Therefore, due to the poor quality of generally available drinking water sources and the obvious lack of adequate centralized systems for delivery of safe water to households in Nigeria, it became expedient to research into low-cost ceramic household water treatment that is able to meet all the water treatment needs (both microbial and chemical) in view to provide an affordable and assessable means for citizens to improve their drinking water quality to acceptable standards.

Therefore, the aim of the research was to develop a ceramic filter for household water treatment that is capable of removing viral and chemical contaminants, as well as microbial contaminants from water using locally sourced materials from Akure, Nigeria.

Methodology

The methodology engaged in carrying out the project followed the defined objectives and proceeded as follows:

Firstly, the raw materials needed were sourced and collected from various locations within Akure. They included clay (kaolin), laterite, charred cattle bones and charcoal derived from the stem of the *cordial millenii* (African drum) tree. The clay and the laterite formed the base material in the ceramic body; the bone char culled from cattle bones was added to remove excess fluoride from water. While the charcoal was used as the burnout material to create more pores in the ceramic and also to possibly introduce activated carbon into the filter to serve as platform for the adsorption and removal of trace and heavy metals like sulphate and lead from water. The materials were then crushed and processed to dry powdered forms.

Ceramic bodies were formulated using an extract of the quadaxial blend of materials. They were batched and milled into ceramic slips, using sodium silicate as deflocculant. The slips were then used to form ceramic filters through the slip casting technique. See **Figure 1** which indicates the three piece working plaster of paris mould derived from the original model made of plastic ball clay while **Figures 2** and **3** show the process of pouring the clay slip and forming of the thin layer of the filter pot through capillary suctioning. The ceramic pot filter design adopted for this project were air dried and fired (subjected to heat treatment) to estimated temperatures of 900˚C (See **Figures 4**, **5** and **6**). At the end of this stage three filter samples were successful. The samples were then subjected to a test for their physical properties which included shrinkage, porosity, and flow rate.

Finally, the effectiveness' of the developed filters were determined by carrying out physio-chemical and microbial analysis on raw and the filter-treated water samples. Raw water samples were collected from water sources which were common to the study area and they included wells, boreholes, and stream. The raw water samples were passed through the filters to obtain the treated water samples (filtrate). The raw and the treated water samples were then taken to the laboratories to test for such parameters as, the microbial load counts, pH, turbidity, Total Solids (TS) and Total Dissolved Solids (TDS); fluoride, sulphate and nitrate concentrations using titration methods; and mineral analysis for metals using the atomic spectrometry.

Figure 1.
Three-piece plaster mould.

Figure 2.
Casting process—pouring in slip.

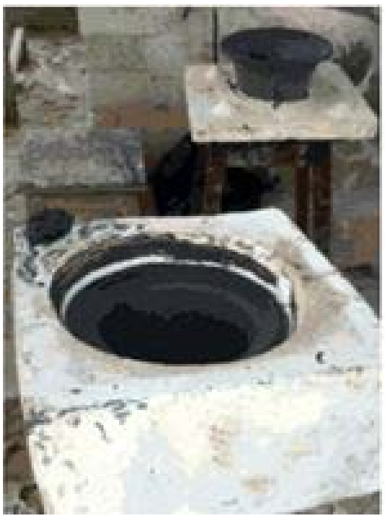

Figure 3.
Casting process.

The Design Consideration for the Filter

The ceramic filter design was adapted from the Potters for

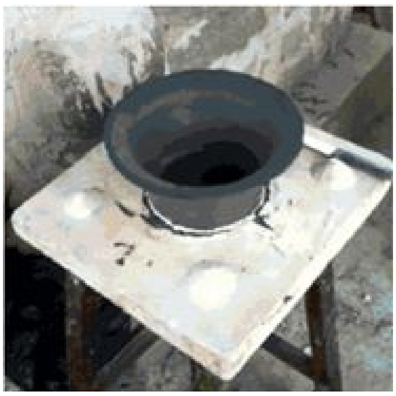

Figure 4.
Demolding the cast filter.

Figure 5.
Drying process.

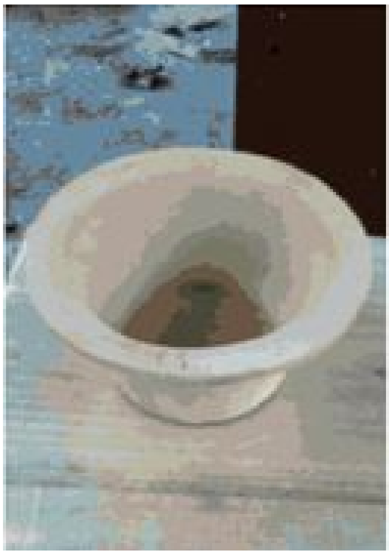

Figure 6.
Fired filter sample.

Peace ceramic pot-shaped filters, which was developed in 1981 by Dr. Fernando Mazariegos of the Central American Industrial Research Institute (ICAITI) in Guatemala. Though other shapes and designs have been given to the ceramic water filters, for the purpose of this project/research, the flat bottom pot filter design was adapted for the reasons highlighted below:

- The effects of the constituent materials were being studied and so less emphasis was placed on shape and design of the sample filters.
- Since the pot filter holds the raw water and is a one-component filter element, it is assumed that there is less risk of recontamination of filtered water in the receptacles through seepages as is possible with the disk and candle-shaped filters.
- Thirdly, with the shaping technique being adapted for the project/research, only the candle or pot-shaped filters will be feasible.
- And sometimes the candle-shaped filters are too fragile and tear when demolding. Hence, the pot shaped filters proved most realisable using the slip-casting method.
- Finally, with the pot-shaped filter, there is the possibility of greater filtration flow rates because the pot filter element engages a larger surface area in filtration. The pot filters also require low maintenance and are easy to use, not requiring any special educational level to operate.

Slip casting was adapted as shaping method in this research as against the commonly used press method for the following reasons:

- To attempt to achieve finer particle size and denser packing in the ceramic body which would result in smaller pores and hence improve the filtration efficiency in the resulting filters.
- Also to achieve low production cost realisable with slip casting, and
- To achieve lower shrinkage values in the ceramic filter, as less plastic materials can be used with slip casting and therefore having more uniform dimensions in the filters.

Results

The results show that the developed filters were effective in the treatment of physio-chemical contaminants detected in the water samples.

All the sample filters gave low shrinkage values which are desirable. The filter sample S24 showed the lowest shrinkage in diameter and this can be attributed to the greater ratio of non-plastic materials in the composition.

The estimated porosity values indicates that sample S24 has the highest porosity (42.26%) and this is resultant of the higher ratio of burnout material (charcoal) in the sample's composition. Increase in porosity is said to result from the burnout material content (Plappally, 2010). Sample S2 with same charcoal content ratio as S5 gave higher porosity of 34.77%, indicating that higher laterite in the composition also varied the porosity of the sample. This corroborates with Brown et al. (2007), that "laterite particles increase the porosity of the fired filter as they do not form same vitrified bonds as the clay between particles".

The flow rate testing results shows that sample S5 gave the highest flow rate while having the lowest porosity (See **Figures 7** and **8**). But Plappally (2010) explains that the pore density distribution across the structural volume of the filter as well as the porosity has major influence on the flow characteristics of a ceramic filter; stating that the velocity of flow is reduced with increased porosity. The researcher was unable to determine the pore distribution in the filters due to inability to access the necessary equipment for the procedure and hence cannot analyze the variation between the estimated porosity values and the flow rate obtained in the developed filters. However, the overall flow rate values of all the sample filters were low. And this can be attributed to the small sizes of the developed filters as compared to the marketed ones. Flow rate is said to increase with increases in the surface area in contact with the water because more pores are being utilized.

In the microbial analysis, three different raw water samples based on their sources were used. The analysis involved testing for bacterial counts, coliform counts, *E. coli* and fungal counts. The results of the stream and borehole samples indicated re-contamination in the treated water samples. But based on the initial results, filter sample S24 was observed to have given the best treatment with percentage reductions in bacterial counts of up to 77% in the well samples and 78% reduction in the borehole samples. Filter sample S5 gave a 100% reduction of coliform in the well water samples.

For the physio-chemical analysis, two different raw water samples based on their sources were used. They were the well and borehole raw water sources. The results of the analysis of some of the parameters are discussed here:

The results show that all the filter samples improved pH and treated TS, TDS and TSS in both classes of water samples. Also all the filter samples treated Lead (Pb) to a 100% reduction in both water samples and fluoride up to 75% reduction in filter sample S2.

While all the filter samples increased Calcium (Ca) levels in both water samples, they increased Iron (Fe) concentrations only in the well water samples. But they gave a reduction of up to 47% of Iron (Fe) concentrations in the borehole water samples.

Though the sulphate (SO^{4-}) concentration values appear incredibly high, all the filter samples showed capacity to treat sulphate in the borehole water samples with reduction levels of up to 76% in sample S24.

It was also shown that all filter samples gave an increased concentration value of Copper (Cu) in both raw water sample classes. Turbidity was recorded only in S2 treated well water and this could be due to possible leaching of some of the ceramic material into the water.

Figure 7.
Flow rate testing.

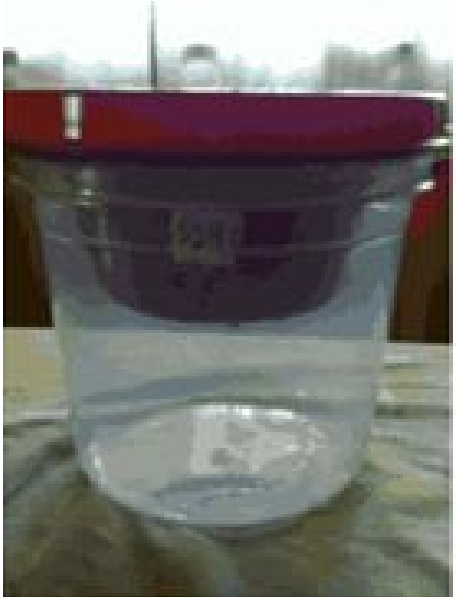

Figure 8.
Filtration process.

Findings and Discussion

The findings are summarized below:

1) Charcoal was a good alternative burnout material in the body compositions, giving good binding and pore-forming qualities up to 50% volume ratio in the body;

2) Increasing quantity of Bone char in the ceramic filter composition increased the filter's ability to reduce fluoride concentration in the treated water sample;

3) Increased charcoal volume ratio in the filter composition increased the porosity of the resulting filter sample. Increased ratio of laterite in the filter body also slightly improved the porosity;

4) Slip casting technique produced good filter samples with even thickness all-round the filter, minimal shrinkage and sufficient dried and fired strength in the body;

5) The developed filters proved to substantially improve the quality of treated water within the scope of the project.

- All the filter samples improved pH in the treated water and gave reduction in Total Solids, Total Dissolved and Suspended Solids values present in the water.
- All the filter samples reduced the fluoride concentration in water in a range of between 33.6% - 75% reduction.
- All the filter samples treated Lead and Sulphate in the water samples with reductions in sulphate concentrations of up to 76.19% and 100% in lead.
- All filter samples gave good microbial treatment results with percentage reductions in microbial load of up to 78%.

The study has proved that the incorporation of bone char in the making of ceramic filters improves the filter's ability to remove fluoride from water. It was indicated from the study that the application of silver to ceramic filters makes them more viable and reduce the problems of recontamination. The study has also shown that increased presence of charcoal in the filter, improves its ability to treat chemical impurities in water such as sulphate and lead.

Conclusion and Recommendation

Based on the findings and discovery in the course of this study, the following observations and recommendations were made:

1) Considering the effectiveness of the slip casting method in the shaping of ceramic pot filters as shown in this study, it is recommended that this technique be employed in the production of ceramic filters as an alternative to pressing thereby eliminating the initial capital cost of purchasing a hydraulic press;

2) Subsequent upon the developed filters' ability to treat both chemical and microbial contaminants in water, it is recommended that the ceramic manufacturing group adopts these filter compositions in their production;

3) It is also recommended that further study and research be carried out on the developed filters to improve upon its performance in water treatment by government and private investors to bring about mass-production of these filters, making it available in most homes thereby alleviating the issue of inadequate supply of safe water in our country and the world.

This project is expected to extend the use of ceramic filters in the household by lifting the existing limitation of the ceramic filters to cover the treatment of chemical impurities in water as well as the microbial and thus making it a near-complete solution to household water treatment needs.

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