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Development and Performance Evaluation of a Ceramic Filter for Point-of-Use Water Purification

In this work, a ceramic filter for point-of-use water purification was designed, fabricated and tested to evaluate its performance in filtering water to the World Health Organisation (WHO) standards. The results of pH of water samples obtained after filtration ranged from 7.68 to 8.11. The range of values obtained after filtration for turbidity, hardness, conductivity, total dissolved solid (TDS) and total suspended solid (TSS) from water samples were 0.07 to 0.55 NTU, 6.0 to 34 mg/L, (1.5 to 3.3) x 10^{-3} *S/m, 4 to 25 mg/L and 0.04 to 0.11 mg/L, respectively, while the filter average removal efficiencies of these parameters were 93.1, 85.1, 91.6, 92.3 and 91.4%, respectively. Comparison of the results with the WHO standards for drinking water showed that the ceramic water filter can provide potable drinking water of required standards.*

***Keywords**: ceramic, drinking water, filter, performance, standards*

1. Introduction

Water is the main component in our body. Human being body consists mainly of water (on average about 70%). Human being liver, for example, is about 90% water, brain 85%, blood 83% and even the bones 35%. Therefore, consuming enough water in our daily life is a must to stay hydrated and healthy [1]. There has been increasing concern to provide water resources in developing countries where what is available may not be potable, and may be harmful to health [2, 3].

Safe drinking water is not available to the majority of the people living in the developing countries. Worldwide, 1.1 billion people of the six billion people on earth (one in six), lack access to sufficient quantities of safe drinking water. About two and a half billion (more than one in three) do not have adequate sanitation services. Together, these facts lead to water borne diseases that kill over six million children every year (about 20,000 children every day) [4].

Water-associated infectious diseases claim up to 3.2 million lives each year, approximately 6% of all deaths globally. The burden of disease from inadequate water, sanitation, and hygiene totals 1.8 million deaths and the loss of greater than 75 million healthy life years. It is well established that investments in safe drinking water and improved sanitation show a close correspondence with improvement in human health and economic productivity. Each person needs 20 to 50 litres of water free of harmful chemical and microbial contaminants each day for drinking and hygiene [4].

Early water treatments were driven by a desire to reduce the visible cloudiness of water, as well as its objectionable taste and appearance. Good taste water has been linked with cleanliness and purity of that water [5]. Some early methods used for water treatment ranged from boiling or placing hot metal instruments in water to the use of crude sand or charcoal filters. As early as 1500 B.C., the Egyptians reportedly clarified water using the coagulant alum, a chemical that causes suspended particles to settle out of water. In addition, filtration has since been established as an effective means of removing particles from water. In the early 1800s, slow sand filtration was beginning to be used regularly in Europe, mainly to improve water's taste and odour. By the late 1800s and early 1900s, slow sand filtration was used by water system in some U.S. cities such as Philadelphia [6]. The current major concern about water quality is the need for water disinfection [7, 8].

Untreated surface water or groundwater is often contaminated with pathogenic organisms of faecal origin. If not, it can become contaminated during transport and storage [9]. Even water treated with a disinfectant often becomes contaminated when collected from a public standpipe and stored at home [10]. A number of different types of pathogens (disease causing organisms) can cause contamination. Major pathogens causing water borne disease are [11]: (i) bacteria (e.g. salmonella, shigella – causing bacillary dysentery, cholera), (ii) viruses (hepatitis A, Hepatitis E, rotavirus), and (iii) other parasites including protozoa (cryptosporidium, giardia, toxoplasma) and helminthes.

The methods used to treat water and make it safe for drinking must be accessible and affordable to all, as well as culturally and environmentally acceptable. These methods are of two kinds: (i) method used by the municipal authorities at central point from where water is distributed; and (ii) method used in individual homes.

A key strategy for improving access to clean water is to enable rural households to purify water in their homes using an appropriate water treatment technology [12]. A recent review of the literature sponsored by the World Health Organization (WHO) concludes that simple, socially acceptable, and low-cost interventions at the household (point-of-use) and community level can improve significantly the quality of household water and reduce the risk of diarrhoeal disease, dehydration, and death, particularly among children [4, 10].

Many studies have been carried out on the efficacy of various types of filter used in household drinking water treatment. Colwell et al. [13] determined that fabric folded four to eight times removed particles and pathogenic organisms greater than 20 microns in size. This can result in the removal of smaller microbes such as *vibrio* cholera that may attach to other particles. Colwell and co-workers implemented fabric filtration in 65 villages in Bangladesh and found a 48% reduction in cholera cases. The method was socially acceptable since unfolded sari cloths are commonly used to filter drinks in Bangladesh. Unfortunately, many pathogens can pass through folded fabric, so it is not entirely effective.

Cloth filters with 100-120 μm pore sizes are commonly used in Ghana to remove the copepods that carry guinea worm vector. These filters are distributed free through the Guinea Worm Eradication Campaign. Ceramic filters rely on gravity to pass water through a porous medium. The filtering pores of ceramic water filters have been measured as 0.2 – 3.0 μm in diameter [14]. This shows that filtering pores of ceramic water filters can remove helminth ova, protozoa, and most bacteria. Two common designs include candle-shaped filters and pot-shaped filters. Both designs use a colloidal silver coating that is reputed to prevent bio-film growth and which may slightly reduce bacteria levels.

Chaudhuri et al. [15] tested the long-term performance of the candle filters. They found good turbidity removal, but they suggest that pore sizes must be less than one micron to remove all bacteria. At such small pore sizes the flow rates would likely go down significantly. Sometimes flow rates can be very slow, and some types of candle filters are expensive. The candles can become clogged over time, especially if water is highly turbid, and they require regular cleaning.

Over recent years, different water filters developed by researchers are: activated carbon water filters, sand filters, reverse osmosis and ceramic filters. In 1981, the Inter American Bank devised a list of criteria for sustainable filters and funded a study to find the best filter [16]. These criteria included fast flowing, effective against bacteria, locally made, inexpensive, and easy to distribute. A drinking water purification system should give final effluent water in line with the World Health Organization's (WHO) guidelines for drinking water quality. Some researchers [17-20] have investigated the use of small-scale decentralized sand filtration units for household use. Sand filtration is more commonly used on a much larger scale in centralized water purification systems for urban centres.

The ceramic filter has many potential advantages as a point-of-use water treatment technology. It can be manufactured with mostly local materials and labour. Since clay pots are often used as storage containers for water, it is a socially acceptable technology that can work year round in different climates. It does not impart an objectionable taste to the treated water. It is designed to remove both turbidity and pathogens and its retail cost is low. In this study, a ceramic water filter was designed and constructed using locally available materials. The filter was tested with water samples collected from various sources in Abeokuta, Nigeria and water quality parameters before and after filtration were monitored and compared with WHO standards for drinking water.

2. Materials and methods

2.1 Design consideration

According to WHO [11], a family of four would consume 10 litres of water per day. Therefore, for an extended family (the common pattern in developing countries) and taking into account peak demand, the need for water per person should be assumed to be 20 litres per day.

The ceramic filter was made from local materials, which included clay and sawdust. Silver solution was applied to the surfaces of the constructed filter element. Ceramic water filter combines the filtration capability of ceramic material with the anti-bacteriological qualities of colloidal silver. Ceramic water filters rely upon porous ceramic (fired clay) to filter microbes or other contaminants from drinking water. The units feature a pore size that should be small enough to remove virtually all bacteria and protozoa, and they work by gravity filtration.

2.2 Description of the Ceramic Filter and construction details

Clay forms the base material of the ceramic filter element. Clay has the following characteristics that make it a suitable material for drinking water treatment. It can be readily accessed in most locations worldwide, it can be moulded easily, and when fired in the kiln it changes chemically to become a strong slightly porous container that does not deteriorate in water. A normal clay pot allows an extremely slow movement of water through naturally occurring pores that exist between the platelets of fired clay. The size of these pores have been measured (by an electron microscope) to be in the range of 0.6 to 3.0 microns (μm) which are capable of straining out most bacteria, protozoa, and helminthes as well as dirt or sediment, and organic matter [21].

Silver was applied to the ceramic water filters. It is known to act as a biocide, capable of inactivating bacteria and viruses. In addition, silver also reduces bacterial growth within the body of the filter and the build-up of biofilm on its surfaces. As the silver solution is applied to the inside and outside of the filter element and is absorbed into the clay pores to act as a biocide, the silver ions (Ag^{+1}) are reduced to elemental silver and form colloids within the body of the filter [22].

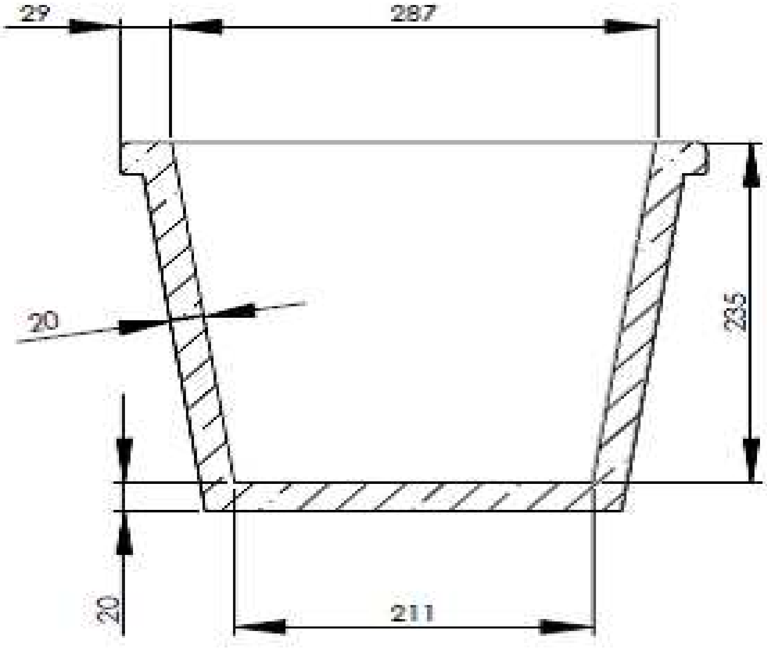
2.3 Production Processes of the Ceramic Filter Element

The followings are production processes involved in the fabrication of the ceramic water filters:

(i) Preparation of raw materials: clay powder, sawdust and water.

(ii) Mixing of the materials to form a mouldable paste. The mixture consists of 30 kg clay powder, 10 kg saw dust and 12.5 litres of water
(iii) Forming clay balls for pressing.
(iv) Pressing of clay cubes into ceramic filter form.
(v) Surface finishing and labelling of pressed filter elements.
(vi) Drying of pressed filter elements to remove initial excess water.
(vii) Firing of filter elements in kiln to finish dehydration and for vitrification.
(viii) Flow rate testing of fired filter elements.
(ix) Painting of silver biocide solution on surfaces of filter elements.
(x) Packaging of ceramic water filter system.

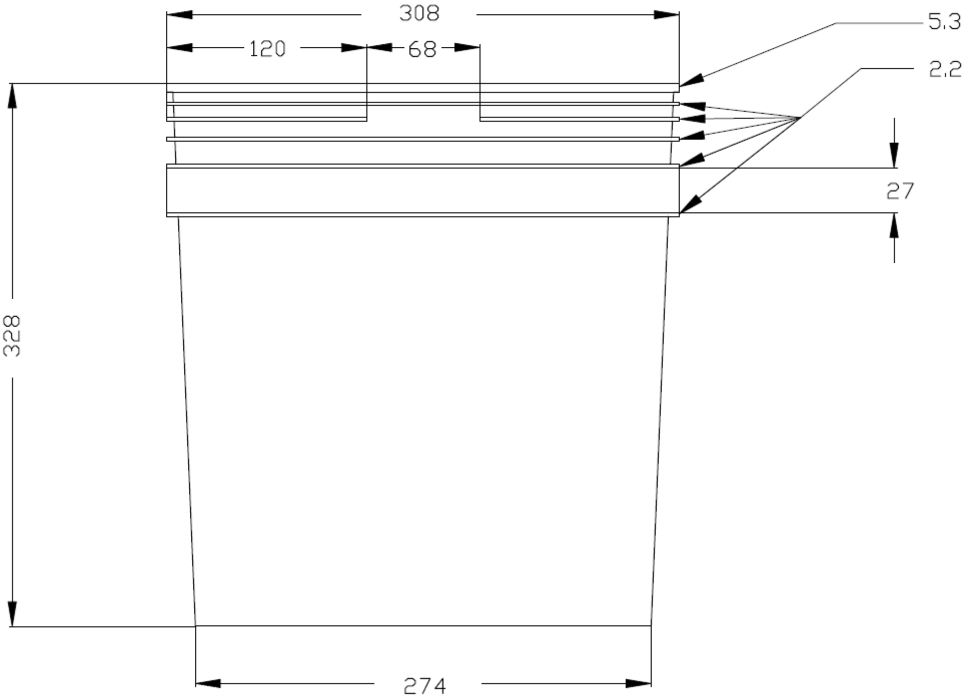
The sectional side view of ceramic filter element is shown in Figure 1 and picture is shown in Figure 2. The capacity of the finished product is 10 litres. Side view of the 20 litres plastic receptacle body is shown in Figure 3 and the complete set-up of ceramic water filter is shown in Figure 4.



All dimensions in mm

Figure 1. Sectional side view of ceramic filter element

Figure 2. Ceramic filter element



All dimensions in mm

Figure 3. Side view of plastic receptacle body

Figure 4. Complete set-up of ceramic water filter

2.4 Tests and experimental analysis

Four samples of raw water from well, rain, river and borehole located in Abeokuta, Nigeria were collected and the tests carried out on the samples before and after filtration included turbidity, hardness, pH, conductivity, total dissolved solids (TDS) and total suspended solids (TSS). The water samples were tested at the College of Environmental Resources Management laboratory, University of Agriculture, Abeokuta and Ogun State Water Corporation laboratory, Nigeria.

3. Results and discussion

Tables 1 to 6 present the results of experiments used to evaluate the performances of the developed point-of-use ceramic drinking water filter. The ceramic filter showed good performance for reducing turbidity, hardness, pH, conductivity, total dissolved solid (TDS) and total suspended solid (TSS) in raw water samples. Table 1 shows the turbidity of water samples from four sources. The turbidity of unfiltered water ranged from 0.92 to 19.7 Nephelometric Turbidity Units (NTU). The WHO standard for drinking water is < 1.0 NTU [11]. The ceramic filter greatly reduced the turbidity of water samples to values below the one recommended for drinking. The values recorded after filtering raw water were in the range of 0.07 to 0.55 NTU and the average turbidity removal efficiency obtained was 93.1%. Therefore, the filter is considered efficient in reducing the turbidity of raw water.

Table 1. The turbidity of water samples

Water source	Turbidity (NTU)		Removal efficiency (%)
	Before filtration	After filtration	
Well	1.24	0.07	94.4
Rain	4.72	0.50	89.4
River	19.7	0.55	97.2
Borehole	0.92	0.08	91.3
	Average		93.1

Table 2 shows the result of the hardness test. The hardness of raw water samples ranged from 38 to 420 mg/L. Some of the values of raw water samples were high when compared with WHO standard of < 80 mg/L for drinking water, but rain water has its hardness within the drinking water standard. This was expected, since rain water is typically rated as soft and groundwater is usually hard. After filtration the hardness of the water samples ranged from 6 to 34 mg/L and the average hardness removal efficiency was 85.1%.

Table 2. The hardness of water samples

Water source	Hardness (mg/L)		Removal efficiency (%)
	Before filtration	After filtration	
Well	110	26	76.4
Rain	38	6	84.2
River	420	34	91.9
Borehole	116	14	87.9
	Average		85.1

Table 3 shows the pH before and after filtration. It is a measure of the hydrogen ion concentration of the water, which indicates whether the water is acidic or alkaline. The result of pH obtained before and after filtration range from 7.47 to 7.80 and 7.68 to 8.11 respectively, which were close to the value of the WHO standard for drinking water (6.50 to 8.50). Table 4 shows the conductivity of the water samples. The conductivity increases as the concentration of ions increases. Conductivity is used as an indicator of the presence of salt or other impurities in the water samples; the purer the water, the lower the conductivity. It is measured in Siemens per meter (µS/m) in SI units. The average removal efficiency obtained for conductivity was 91.6%.

Table 3. The pH of water samples

Water source	pH	
	Before filtration	After filtration
Well	7.47	7.68
Rain	7.76	8.07
River	7.71	7.85
Borehole	7.80	8.11

Table 4. The conductivity of water samples

Water source	Conductivity (S/m) x 10^{-3}		Removal efficiency (%)
	Before filtration	After filtration	
Well	42.3	3.3	92.2
Rain	15.8	1.9	88.0
River	18.3	1.5	91.8
Borehole	39.7	2.3	94.2
	Average		91.6

Table 5 shows the values of total dissolved solid (TDS) contained in both the raw and the filtered water samples. High levels of TDS in water may cause objectionable taste and have laxative effect. From the table, it can be seen that the initial value of TDS in the raw water ranged from 91 to 212 mg/L and the values of TDS dropped to the range of 4 to 25 mg/L after passing through the ceramic filter. The average removal efficiency obtained for TDS was 92.3%.

Table 5. The total dissolved solid (TDS) of water samples

Water source	TDS (mg/L)		Removal efficiency (%)
	Before filtration	After filtration	
Well	212	25	88.2
Rain	76	4	94.7
River	91	6	93.4
Borehole	199	14	92.9
	Average		92.3

Table 6 shows the total suspended solid (TSS) contained in raw and filtered water samples. The results of the TSS before and after filtration range from 0.50 to 1.18 mg/L and 0.04 to 0.11 mg/L, respectively. These results have shown that the ceramic element performed efficiently in reducing both the total dissolved solid and the total suspended solid.

Table 6. The total suspended solid (TSS) of water samples

Water source	TSS (mg/L)		Removal efficiency (%)
	Before filtration	After filtration	
Well	0.98	0.08	91.8
Rain	1.12	0.10	91.1
River	1.18	0.11	90.7
Borehole	0.50	0.04	92.0
	Average		91.4

4. Conclusion

In this study, a ceramic filter for point-of-use drinking water purification system was designed, constructed with locally sourced materials and tested to evaluate its performance. The system comprises of the ceramic filter element and plastic receptacle. The plastic receptacle body housed both the filtered water and the filter element in its different compartments. Raw water samples from wells, borehole, river and rain were collected at various sources in Abeokuta, Nigeria and were subjected to a series of tests before and after filtration. The result of pH of water samples obtained after filtration ranged from 7.68 to 8.11, which is within the range of the WHO standard for drinking water. The range of values obtained after filtration for turbidity, hardness, conductivity, total dissolved solid (TDS) and total suspended solid (TSS) from water samples were 0.07 to 0.55 NTU, 6.0 to 34 mg/L, (1.5 to 3.3) x 10^{-3}S/m, 4 to 25 mg/L and 0.04 to 0.11 mg/L, respectively, while the filter average removal efficiencies for these parameters were 93.1, 85.1, 91.6, 92.3 and 91.4%, respectively.

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