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Research Article

Water Purification Using Ceramic Pots Water Filter

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Abstract

In this study, ceramic pot filters are made from clay and burn-out materials (sawdust) that give pore sizes capable of capturing contaminants. Manufacturing specifications were selected to achieve some results. Clay and sawdust are mixed in a 50% volume ratio each and sawdust was subjected to hot water extraction to give a treated sample. Filters produced comprised of untreated, treated, and a mixture of treated and untreated sawdust samples, some of which were dipped in a solution of silver nanoparticles while others were not dipped (treated undipped, treated dipped, mixed dipped, mixed undipped, untreated undipped, untreated dipped). The effectiveness of the produced filters for the removal of contaminants such as dissolved solids, turbidity, and metals was tested using water collected from the Ikeji Arakeji River in Osun, Nigeria. The results showed the filter with treated sawdust undipped in a solution of silver nano gave the best result in the removal of the contaminants. Also, the filter with the mixtures of treated and untreated sawdust gave a better result compared to the standard. While the standard gave a better result than the untreated undipped ceramic filter pot. In conclusion, with proper cleaning and maintenance of the filters, they can effectively provide treated water suitable for drinking to rural people affected by polluted water sources.

Introduction

The water crisis affects millions worldwide and it is expected to worsen over the coming years and decade. It was estimated that in 2010, 1.8 billion people consumed water deemed “unsafe” and 783 million regularly used water sources unprotected from contamination (USEPA, 2002) [1-3] Children are the most affected by ingestion of the contaminated water. Every year, 3.4 million children die as a result of diarrhea and other diseases caused by water-borne microbes making it the second leading cause of death of children, especially in low- and middle-income countries (Onda, et al. 2012; Wu, et al. 2011; Larson, et al. 2023) [4,5].

Though many factors contribute to water contamination, climate change, poor infrastructure, and failed aid projects continue to exacerbate the problem. Climate change often stresses water supplies in areas that are already water-scarce, forcing residents to use unsanitary sources [6,7]. The continued lack of sanitation infrastructure in many countries also leads to contamination of drinking water and affects health and development in these [8,9].

Water purification solutions must fulfill a variety of requirements in order to be successful. First and foremost, they must improve health by filtering out particulates as well as the majority of harmful microbes [10]. However, the technologies must accomplish this while ensuring that clean water is still affordable to those in extreme poverty. Additionally, technologies must be appropriate and applicable wherever water quality must be improved. Successful processes also should not further contribute to other health or environmental ailments such as fossil fuel pollution and the resultant respiratory illness. Both the filtration process and the consumable water must be socio-culturally acceptable to the users. For instance, operation and maintenance must be within local education levels and different–tasting water should need to be remedied or avoided. Finally, successful cleaning processes must resolve how to preserve sanitation while storing water (or how to clean only what is needed at the time (EPA, 2023) [11].

In the further pursuit of solutions to providing safe drinking water to those in need, point–of–use household water treatment has emerged as a complementary solution to centralized water supply systems [12]. Household ceramic water filters, in particular, offer an affordable and effective means of treating water to a standard suitable for drinking [13-15]. The present study is therefore aimed at developing ceramic filters using clay and sawdust as burnout materials for water treatment.

Materials and methods

Sample collection and preparation

The fresh colloidal water used in the flow rate determination and other studies were collected at Ikeji Arakeji town in Oriade local government Area of Osun state, Nigeria, and the water is known to be consumed by a lot of worshippers because the source is located within a religious center.

The clay grogs were obtained in a mine site at Itori village Ewekoro local government Area of Ogun State, Nigeria. It appeared multicolored when freshly excavated. The appearance is because it is made of red and black clay mixture locally known as Iro and Ewuya respectively in the local dialect. This color difference shows that red clay is about 70% to 75% present in the mixture which made the sample suitable for use for ceramic water filters as a result of its high plasticity as compared to other types of clay (Figure 1). all the samples used in this study were readily available and accessible.

Pretreatment of clay sample

The clay grogs were reduced into smaller pieces and sun-dried for about four days under constant sunlight before it was further pulverized using mortar and pestle to a powdery state. The pulverized clay was sieved to 0.425 mm particle size (Figure 2), thoroughly agitated, and re-dried to ensure minimal moisture retention.

Figure 1: Experimental clay sample.

Figure 2: Pulverised and sieved clay sample.

Pretreatment of sawdust samples

The sawdust particles were washed continuously with hot water at about 80 °C for about 1 hour in a thermo-coupled voltage regulator-aided water bath. The sawdust was poured into different water baths filled with deionized water and stirred periodically for about an hour before they were drained of water and the extract was kept in a container for further analysis. The hot water-treated sawdust was sun-dried to a moisture content of about 12% before it was sieved to 2 mm particle size and packed in an airtight container (Figures 3a,b) to prevent further absorption of moisture and bacteria invasion.

Phytochemical screening

The phytochemical screening to ascertain the presence of the polyphenolic compounds in the sawdust samples was carried out and described below.

Test for alkaloids: About 0.2 g of the extract was warmed with 2% H_2SO_4 for 2 minutes, it was filtered And a few drops of Dragendoff Reagent were added. The formation of an orange-red precipitate indicated the presence of alkaloids [16].

Test for glycosides: Extracts from the sawdust were shaken with deionized water and filtered. The filtrate was boiled with drops of Fehling's solution A and B for two minutes. The presence of reducing sugar was indicated by the formation of an orange-red precipitate on boiling with Fehling's solutions. The extracts were hydrolyzed with dilute HCl and neutralized with NaOH solution. A drop of Fehling's solution A and B were added. Red precipitate indicated the presence of glycosides [17].

Test for saponins: About 0.2 g of the extracts were shaken with 5 cm^3 of deionized water and then heated to a boil. Frothing showed the presence of Saponins [18].

Test for flavonoids: Small quantities of the extracts were dissolved in diluted NaOH and hydrochloric acid was added. A yellow solution that turned colorless indicated the presence of flavonoids [19].

Test for tannin: 1 g of the extract was mixed with 10 cm^3 of water to make a decoction. 5% iron (III) chloride solution was added drop by drop to 2-3 cm^3 extract. A blue-black color

Figure 3: Pretreated sawdust samples; (a) Sieved sawdust; (b) Stored sawdust samples.

indicated the presence of tannin. The color produced is best detected by adding diluting 1 cm^3 of the tannin extract in a test tube filled with deionized water and then adding $FeCl_3$. [20].

Test for sterols: 0.5 g of the extract was dissolved in 2 cm^3 of chloroform H_2SO_4 and was added carefully to form a lower layer. A reddish-brown interphase indicates the presence of sterols [17].

Production of ceramic water filter

The clay sample used in the ceramic water filter was dry-mixed with sawdust samples. The mixture was mixed based on a volume ratio of (1:1) of clay and sawdust respectively [21,22]. The mixture was further subjected to thorough sieving using a 1 mm pore-size mesh to ensure proper homogenous mixing before deionized water was added at intervals until the required plastic texture was obtained in the resulting matrix (Figure 4).

The matrix was molded into a frustum shape using a press with appropriate pressure (Figure 5). Different productions of filters were carried out using the untreated and hot water pre-treated sawdust samples at different mixing ratios.

The molded frustum-shaped ceramic filters were air dried for two weeks at room temperature before they were arranged in a locally made clay kiln and fired, the temperature was maintained to 85 °C. This was done at a rate of 45 °C per hour and was further increased to 100 °C per hour with a gradual and steady increase in the temperature. During the heating process, the sawdust burnt off at a temperature of approximately 500 °C leaving behind micro pores in the filter. The variation in the temperature was measured using a type K thermocouple. The furnace was cooled to room temperature (Figure 6) and the fired filters were packed and aired at room temperature for a week.

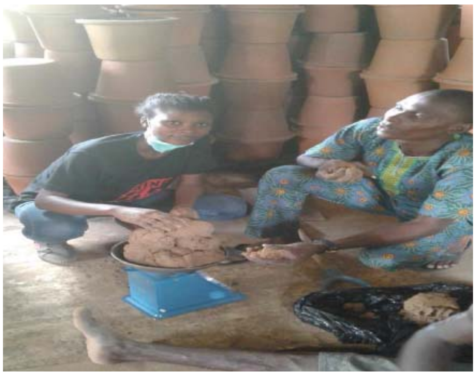

Figure 4: Weighing of the clay-sawdust matrix before molding.

Figure 5: Molding press for the ceramic filter.

Some of the ceramic filters were later impregnated with colloidal silver nanoparticles by dipping them in a solution of silver nanoparticles for disinfection purposes. The dipped filters were air-dried for another week before packaging.

Flow rate determination

Filters were soaked in deionized water for about 3 to 6 hours to ensure saturation before the flow rate determination. Flow rates were determined by pouring the collected colloidal water into the ceramic filter (Figure 7) and placing the filtering ceramics in a graduated glass container (Figure 8) the amount of water that filters through after each hour was measured and recorded.

Analyses of raw and filtered water samples

The following analyses were carried out on the raw and filtered water.

Figure 6: Sun-drying of ceramic filters.

Figure 7: Water saturated ceramic filter just before filtration.

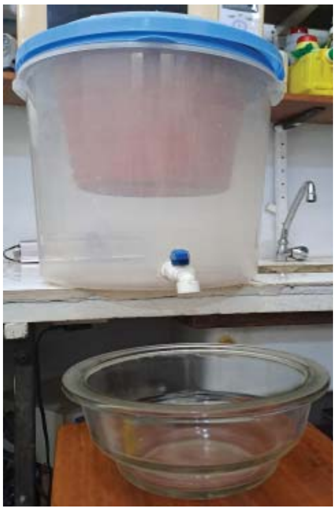

Figure 8: Experimental setup for water filtration.

Elemental analysis: The raw and filtered water samples were analyzed for the presence of Zinc (Zn), Cadmium (Cd), Manganese (Mn), and Lead (Pb) using Atomic Absorption Spectroscopy (AAS) using the flames of each of these metals with detection limits of 0.01, 0.02, 0.01 and 0.02 mg/L respectively for each determined metal.

Turbidity test, Total Dissolved Solids (TDS), and pH determination: The turbidity test was carried out with the use of a turbidimetry meter to determine the clarity of water samples while the Total dissolved solid test that showed the level of the dissolved solids combining the organic and inorganic content in the water samples was also determined.

The pH of the various water samples in the study was determined after the calibration of the pH meter with standard buffers of 4, 7, and 10.

Results and discussion

Phytochemical substances

The presence of phytochemical substances which are polyphenolic in nature, water, and alkali-soluble are known to inhibit the setting of composite and their removal or reduction in their concentration in constituting cellulosic materials facilitated the bonding compatibility to agricultural residues [23]. The hot water extraction removed most of these inhibitory substances thus enhancing the compatibility of the clay particles with the lignocellulosic particles [24]. The results showed a close similarity between the sawdust used as a standard and the one used in this study in the sense that the experimental sample sawdust was found to contain a relatively higher amount of these polyphenolic compounds as presented in Table 1 compared to the sawdust used in the standard that contained a lower amount of alkaloids but flavonoids were absent. Though these phytochemical substances are known for their medicinal properties in man, their presence in potable water can alter some of their properties such as pH, color, and taste. The hot water treatment can be said to be appropriate since it serves a dual purpose of removing substances that could inhibit the setting in the clay composite and also reduce the potability of the water.

Flow rate

With the sawdust used as the burnout material at the optimal performing form, the effluents obtained from the filtration processes ranged between 1 and 2 liters with the maximum effluent obtained being 1.70 liters obtained with the use of hot water treated sawdust sample (Table 2). It was observed that the flow rate was slow enough to allow adequate contaminants filtration and it was quick enough to supply adequate filtered water for drinking. After about three hours decrease in flow rate was observed due to a decrease in the level of influent water [25], indicating that the higher the quantity of the influent water, the higher the flow rate. This could be attributed to the increased pressure due to gravity.

The initial flow rate was observed to be much greater than other flow rates measured over subsequent hours, which could be due to the deposition of colloids as the turbid water was being filtered. It was observed that the flow rates of filters with silver Ag were slightly higher than those without the impregnation of silver, particularly the hot water-treated ones. This could be assumed to be due to the absence or reduction in the polyphenolic phytochemical substances that could form aggregates with existing heavy metals in the water and in the process form clogs that could reduce the pore sizes which in turn reduces the flowrate of the eluting water over time. In another vein, the ability of Ag ions to form chelates with the colloids possibly pulled them together and reduces their spread thus creating more room in the pores for the eluting water to pass through freely. This should account for

Table1: Phytochemical Components in Sawdust.

Compound	Sawdust	
	Standard	Experimental
Tannins	–	–
Glycosides	–	–
Saponins	++	++
Flavonoids	_	+
Steroids	–	–
Alkaloids	++	+++

Table 2: Flow rate of water samples.

Sample	Minimum Flow rate (Litre/hr)	Optimum Flow rate (Litre/hr)
Standard ceramic filter	0.0225	1.35
Treated undipped ceramic filter	0.0250	1.50
Treated dipped ceramic filter	0.0283	1.70
Mixed undipped ceramic filter	0.0243	1.45
Mixed dipped ceramic filter	0.0267	1.60
Untreated undipped ceramic filter	0.0233	1.40
Untreated dipped ceramic filter	0.0258	1.55

Legends:
Dipped: Dipped in silver nanoparticle solution
Undipped: Not dipped in silver nanoparticle solution
Untreated: Non-hot water treated sawdust sample
Treated: Hot water-treated sawdust sample
Mixed: A mixture of Hot water-treated and non-hot water-treated sawdust

the increase in the flow rate observed in the hot water treated and silver nanoparticle-dipped water filters. All the filters from the treated sawdust samples gave a higher flow rate as compared to the untreated ones.

A correlation has been found between clay content flow rate and pore size [26]. The mineral composition of clay might play an important role in the purification process which may pose a problem when not properly selected. To achieve the desired flow rate, the plasticity of clay [27,28] and the size of the burnout material (Hagan, et al. 2009) will influence the quality of burnout material added to achieve the flow rate.

The size might also affect the precise measure of effluents when burnout material is measured by volume because burnout materials such as sawdust can affect both the flow rate and microbiological efficacy of the filter [29]. Therefore, different mix ratios may be appropriate for use depending on burnout materials chosen for use with the quantity of the burnout material being slightly higher for an increase in the flow rate but a slight decrease in the efficiency. Size might also affect precise measuring when burnout material is measured by volume, burn-out materials can affect both the flow rate and microbiological efficacy [29]. Therefore, different mix ratios will apply depending on the burnout materials chosen for use.

pH

The pH of the raw water fell within the acceptable range for drinking water (6.5 – 8.5) according to the United State Environmental Agency (USEPA) but those of the filtered water were slightly lower than the pH of 7.0 obtained for the raw water (Table 3) but were still within the acceptable range for drinking water [30]. This could be attributed to the removal of contaminants such as metals that possibly raised the pH of water.

Turbidity

The clarity of the raw and filtered water as expressed as turbidity as presented in Table 3 ranged between 1 and 4 NTU. These values were lower than the expected values for drinking water which should not be greater than 5 NTU but the best should be 1 NTU [31,32]. Filters produced from the hot water-treated sawdust gave better results for those dipped and undipped in silver nanoparticles than filtrates from filters made from the untreated sawdust which were slightly higher.

Table 3: pH, Turbidity, and total dissolved solids of raw water and effluents.

Filtered water source	pH	Turbidity (NTU)	TDS (ppm)
Raw water	7.00	4	274
Standard ceramic filter	6.86	2	221
Treated undipped filter	6.80	1	214
Treated dipped filter	6.70	1	236
Mixed undipped filter	6.80	1	218
Mixed dipped filter	6.73	1	246
Untreated undipped filter	6.98	2	241
Untreated dipped filter	6.51	2	196

The relatively higher turbidity of 4 TNU detected in the raw water may be due to the high turbidity levels displayed by surface water during periods of high rainfall because it is surface water (APHA/AWWA/WEF, 2012).

Total Dissolved Solids (TDS)

The existence of high levels of Total Dissolved Solids (TDS) in drinking water may affect the taste and palatability of the water. With the standard TDS, values are set as *excellent* when the values range between 50 and 150, good for values ranging between 150 and 250, and fair for values between 250 and 300 while values greater than 300 ppm are considered poor and not good for drinking water (WHO). The presence of high levels of TDS may affect the taste of the drinking water. The palatability of drinking water has been related to taste as follows; when it is less than 300 mg/L it is excellent, when it is between 300 and 600 mg/L it is good, it is fair when it is between 600 mg/L to 900 mg/L, when it is between 900 mg/L and 1200 mg/L it is poor. Anything greater than 1200 mg/L is not acceptable [33,34]. All the filtered water had values much lower than 300 ppm and could be considered drinkable with the filter made from the untreated sawdust dipped in silver nanoparticles giving the best result of 196 ppm. (Ref). The filters proved to substantially improve the quality of water treated because it has the ability to reduce TDS and improve pH and turbidity concentration, in the treated water sample. Water-containing contaminants, both biological and chemical, whose concentrations are above the permissible levels are usually of great concern to human and animal health.

Selected heavy metal content

Chemical contaminants such as Manganese (Mn), Zinc (Zn), Cadmium (Cd), and Lead (Pb) were studied [35-37]. The results presented in Table 4 showed that there was no detectable amount of lead in the raw water so it was not suitable for use in determining the amount of lead in the filtrate. Detectable amounts of Manganese were found in the raw water sample and most of the effluents from the filters gave lower concentrations of the manganese except for three filters that were dipped in silver nanoparticles. Mn is present

Table 4: Determined heavy metals in raw and filtered water.

Filtrate Source	Metal Concentration (mg/L)			
	Pb	Mn	Zn	Cd
Raw Water	-0.184	0.046	-0.0170	0.024
Standard Ceramic Filter	-0.058	0.040	0.0012	0.021
Treated Undipped Ceramic Filter	-0.128	0,043	0.0041	0.022
Treated Dipped Ceramic Filter	-0.149	0.096	0.0041	0.027
Mixed Undipped Ceramic Filter	-0.050	0.027	0.0035	0.033
Mixed Dipped Ceramic Filter	-0.126	0.071	0.0059	0.031
Untreated Undipped Ceramic Filter	-0.042	0.035	0.0046	0.032
Untreated dipped Ceramic Filter	-0.028	0.065	0.0071	0.036

Legends:
Dipped: Dipped in Ag nanoparticle solution
Undipped: Not dipped in Ag nanoparticle solution
Untreated: Non-hot water treated sawdust sample
Treated: Hot water-treated sawdust sample
Mixed: A mixture of Hot water-treated and non-hot water-treated sawdust

in clay as magnesia and the majority of it is encapsulated in a clay matrix with a tiny percentage of particles exposed on the body surface. Therefore, the presence of Mn in the effluents could be attributed to the possibility of the displacement of manganese from the clay filter resulting from leaching even though the concentration of manganese in the effluents from these three filters (Table 4) was still less than the prescribed standards of the World Health Organization of 0.02 mg/L [31].

Zinc was not detectable in the raw water but was found in the effluents even though the concentrations detected were lower than the minimum standards of 3.00 mg/L stipulated by the World Health Organization. The silver nanoparticle dipped filters gave relatively higher values than the undipped and the obtained values were still very much below the prescribed standard for drinking water. Clay is known to contain Zn as one of its essential metals of which Ca, Fe, and K complete the series while As and Pb are the major toxic metals [38] this could be the possible source of Zn in the filtered water.

Though some of the Cd levels found in some of the filtered water were higher than the concentration detected in the raw water, the values obtained were lower still lower than the WHO standards for drinking water [39]. This can be attributed to the ability of Cd to get adsorbed on the surface of clay but the degree of metal sorption to clay is usually impacted by the solution pH and ionic strength. Metals, other than Cd can also get accumulated through flocculation of water which usually leads to metal accumulation in marginal marine settings. These metals can be desorbed when transitioning between fresh water and seawater pH and ionic strength conditions [40]. Clay minerals as a source of cadmium to estuaries. The increase in ionic strength has a greater impact than an increase in the pH. The higher concentrations of metals obtained in the silver nanoparticle dipped filters may be due to the displacement of these metals from the ceramic filters by the Ag due to their lower activity as compared to silver as expressed in the activity series.

Though the metal concentrations obtained for the effluents were lower than those of the standards for drinking water [41]., it might be necessary to subject the filters to desorption with solutions of the appropriate pH and ionic strength to rid them of the excessive constituent metals that may affect the efficiency of the ceramic filters [40] present in them. Naturally, the clay of which the filter is composed determines which elements are present in the effluents [41,42].

These metals can be desorbed when transitioning between fresh water and seawater pH and ionic strength conditions [40]. Economically, the components of clay and burnout materials are both readily available, and ceramic filters have the ability to remove particulates, turbidity, and Total Dissolved Solids (TDS). In developing countries, household-scale ceramic filters are being used as a better treatment option for both unpurified and insufficiently disinfected water at the household level [43-45]. It was generally observed that the water sample contain relatively low trace metals.

Conclusion

This study concludes that contaminants were reduced from the raw water sample. The different ceramic water filters produced were all effective in the purification of colloidal water by reducing the turbidity, lowering the total dissolved solids, and improving the pH value. The materials used in the production are locally available and some are waste products, through the production process, the environment is made clean. The filters produced with hot water-treated sawdust (treated sample) proved to be more effective in the treatment of water compared to other samples produced (mixture and untreated samples). It is also important to soak the ceramic filters in water before use to enhance the siphoning effect and the removal of metals, though in very minute quantities, existing in clays.

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