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A Simple Ceramic Water Filter for Water Purification in the Rural Area

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Abstract: Most rural dwellers in Nigeria are living in areas where tap water are not available and they depend mainly on ponds and streams water for drinking which in most cases the water have been contaminated with pathogens, guinea-worm and agricultural waste products. This study was conducted to develop simple ceramic filters for purification of water. Two ceramic water filters were produced using kaolinite-clay and sawdust. Percentage compositions of sawdust to kaolinite-clay for the ceramic water filters by volume were 40%-60% (F_1) and 50%-50% (F_2). The Sawdust (from hardwood) and kaolinite-clay were ground and sieved through 0.075 mm sieve. The kaolinite-clay and sawdust were thoroughly mixed, soaked in water for 24 hours, mixed again and heated inside a furnace at 900-950°C for 8 hours. Each filter has 220mm diameter at the top, 180mm diameter at the bottom, 240mm in height and 20 in thickness. Water samples were collected after filtration and analyzed. The flow rate of F_1 and F_2 were 77 mL/h and 108 mL/h, respectively. Total coliform of raw water was 2.08 cfu/ml but total coliform was not detected after filtration through the two filters. The filters reduced water hardness, turbidity, Calcium, Chloride, Iron, Magnesium and Zinc from the water.
Keywords: Ceramic filter; kaolinite-clay; potable water; contaminated water; surface water; total coliform

1. Introduction

Rural dwellers in most parts of Nigeria don't have access to tap water and they have problem of getting potable water for drinking and other domestic uses. The rural dwellers in some parts of the country in Nigeria depend mainly on surface water such as pond, stream, river, shallow well and these sources of water in the rural areas are normally contaminated with pathogens, guinea-worm, chemicals and agricultural waste products. Water is essentially needed for survival of man and animal in every location. Drinking of contaminated water could lead to water-borne diseases such as diarrhea, typhoid, cholera and other deadly diseases [1]. [2] reported that about 3.4 million of children die yearly due to diarrhea and other diseases that are caused by water-borne pathogens. [3] reported that treatment of water in the rural areas is very difficult and expensive due to lack of facilities for water treatment in the rural areas; most rural areas don't have electricity to power water treatment plant and lack of petrol or diesel in rural areas to run the machine. All these factors make treatment of water in the rural areas difficult for rural dwellers.

There is a need for developing simple and portable household water treatment equipment such as ceramic water filter, slow sand filter and other simple water treatment for the rural dwellers to prevent water-borne diseases in the rural areas of Nigeria. [4] pointed out that ceramic water filter is a simple water purification equipment which could be used at household level. Ceramic water filter does not require electricity or mechanical power or machine to run it which is not available in most rural areas of the country. [5] stated that ceramic water filter is normally constructed from clay and sawdust (combustible material) and these materials are available in the most parts of Nigeria. Sawdust is the micro-pores forming agent in the ceramic water filter when it is heated at high temperature of 800 - 950 °C [6].

[7] reported that ceramic water filter is adequate for the removal of turbidity by 83 - 99% and could remove bacteria by 98 - 100%. [8] indicated that ceramic water filter is effective for the removal of more than 90% iron from the water. [9] also pointed out that ceramic water filter acts as a filter to remove chemicals and bacteria from the contaminated water thereby making the water safe for drinking. The flow rate of water in the ceramic filter depends on the porosity of the ceramic water filter which also depends on the percentage composition of the sawdust to the clay in the filter [10]. [11] reported that the flow rate of ceramic water filter increases with increase in the percentage composition of sawdust (combustible material) that is mixed with the clay. High percentage composition of sawdust in the ceramic filter increases the porosity of the filter but could affect the effectiveness of the removal of total coliform from the contamin ated water. The thickness of the ceramic filter also affects the flow rate and effectiveness of the removal of the pathogens and other contaminated materials. The objectives of this study were to develop a simple ceramic water filter that is suitable for rural dwellers and to carry out the performance evaluation of the filter.

2. Materials and Methods

2.1 Location of the study

The study was carried out at the Department of Agricultural and Biosystems Engineering, University of Ilorin, Ilorin, Kwara State, Nigeria. Ilorin lies on latitude 8°30^{1}N and longitude 4°35^{1}E, 340 m above the mean sea level and Ilorin has about 1,300 mm annual rainfall.

2.2 Design equations for the volume and flow rate of the ceramic water filter

The expected volume of the conical frustum-shaped ceramic water filter at the design stage was assumed to be 7 litres (7 L) and the volume was determined using Equation (1). The flow rate of water from the side of the ceramic water filter defers from the flow rate through the bottom of the diameter of the filter and thickness of the filter also affects the flow rate. Filtration of water occurs in all sides of the ceramic filter and through the bottom of the filter. The flow rate of water through the bottom of the ceramic filter is based on Equation (2) given by [12] while the flow rate through the sides of the frustum-shaped ceramic filter is governed by Equation (3) reported by [13]. The total flow rate from a frustum-shaped ceramic water filter is based on Equation (4) given by [12].

$$V_c = \frac{1}{3}\pi h\left(R^2 + Rr + r^2\right) \quad \textbf{(1)}$$

$$Q_b = \frac{k\pi r_b^{\ 2}\rho g h_t}{\mu t_b} \quad (2)$$

$$Q_s = \frac{\pi k\rho g}{\mu t_s}\left[r_b h_t^{\ 2} + \frac{\tan\theta h_t^{\ 3}}{3}\right] \quad (3)$$

$$Q_t = \frac{k}{\mu}\pi\rho g h_t\left[\frac{r^2{}_b}{t_b} + \frac{r_b h_t}{t_s} + \frac{h_t^{\ 2}}{3t_s}\tan\theta\right] \quad (4)$$

where Q_b is the flow rate through the bottom of the ceramic filter (m^3/s), Q_s is the flow rate through the sides of the ceramic filter (m^3/s), k is the hydraulic conductivity of the ceramic filter (m/s), r_b is the radius of the bottom of the ceramic filter (m), ρ is the density of water (kg/m^3), g is the acceleration due to gravity (m/s^2), h_t is the height of the water in the ceramic filter (m), μ is the dynamic viscosity (N-s/m), t_b is the thickness of bottom of the ceramic filter (m), t_s is the thickness of the sides of the ceramic filter (m), Q_t is the total flow rate from the bottom and the sides of the ceramic water filter (m^3/s) and θ is the angle of inclination at the corners of the frustum from the bottom of the filter (°).

2.3 Description and construction of the ceramic water filter

The ceramic water filter was constructed using kaolinite-clay and sawdust. Two ceramic water filters were constructed with the percentage compositions of sawdust to kaolinite-clay for the ceramic water filters by volume were 40% - 60% (labeled as F_1) and 50% - 50% (labeled as F_2). The two filters were conical frustum-shaped with each filter has 220 mm diameter at the top, 180 mm diameter at the bottom, 240 mm in height and 20 in thickness and has a volume of 6.862 litres which was calculated using Equation (1) with dimensions stated. The sawdust was obtained from hardwood at sawmill Ilorin, Kwara state, Nigeria. The kaolinite-clay (6 kg) was purchased at Okelele Clay Pot making factory, Ilorin. Both the sawdust and kaolinite-clay were ground and sieved through 0.075 mm sieve.

The kaolinite-clay and sawdust were thoroughly mixed, soaked in water for 24 hours and then properly mixed again. The bottom of the filter firstly constructed and allowed to dry for 24 hours. The properly mixed kaolinite-clay and sawdust was put in the mould and compressed in order to remove void and to make it compact. The mould with the material was placed on the constructed base of the filter, smoothed with the mixed kaolinite-clay and sawdust and allowed to dry. The two ceramic water filters were air-dry for 24 hours and then allowed to sun-dry for 3 days after which the filters were heated inside a furnace at 900 - 950 °C for 8 hours to burnout the sawdust and create micropores in the ceramic filter for the filtration of water. Each of the ceramic water filters is put in the 15 litres transparent bucket. The two 15 litres transparent buckets were put on top of each other with the upper bucket containing 5 holes of 10 mm diameter round centre of the bucket. The upper bucket was connected with the lower bucket with 6 pieces of 12.7 mm diameter pipe and 50 mm long through the cover of the lower bucket to drain the filtered water into the lower bucket (storage tank). The storage bucket at the bottom has a tap to drain the filtered water from the ceramic water filter.

2.4 Determination of flow rate of the ceramic water filter

The water used for the performance evaluation of the ceramic water filter was surface water collected at the downstream (50 m away from the dam) of the University of Ilorin dam. Six (6) litres of water was poured in the ceramic water filter and volume of water in the lower bucket after 3 hours 30 minutes was measured using 1000 ml glass measuring cylinder. The flow rate (discharge) was determined using Equation (5).

$$Q = \frac{V_d}{t} \tag{5}$$

Where Q is the flow rate (m^3/s or litre/h), V_d is the volume of water drained or filtered through the ceramic filter (litre) and t is the time taken to drain the water from the filter (second or hour).

2.5 Determination of pH, water hardness and turbidity

Water samples were collected from the two ceramic water filters and raw water (control). The water was poured in a beaker and probe was used to measure the pH, water hardness and the turbidity.

2.6 Determination of Calcium, Iron, Magnesium, Manganese and Zinc

The water samples collected for chemical were firstly digested using aqua regia method. A 50 ml of acidified water was measured into a clean 250 ml digestion flask, 15 ml of concentrated nutric acid and 5 ml of concentrated HCL (3:1) was added. The digestion flask was heated on a hot plate for about 15 minutes at 100 °C for the brownish fumes to be expelled to show that the water sample had been digested as stated by [14]. The digestion flask was then removed from the hot plate and allowed to cool at room temperature, then filtered through whatman number 1 (filter paper) into a 50 ml standard flask and into plastic reagent container for atomic absorption spectroscopy. Calcium, Iron, Magnesium, Manganese and Zinc were determined using the standard methods given by [15] and [16].

2.7 Determination of paired t-test statistical analysis

The statistical analysis used was the Paired t-test to determine if the effect of passing the water through the ceramic filter was significant or not. The mean difference between of the results of filtered water and that of control was determined. The mean, the standard deviation, the standard error and the t-test values were determined using Equations (6), (7), (8) and (9), respectively as reported by [17].

$$\bar{d} = \frac{\sum d}{n} \tag{6}$$

$$\delta = \sqrt{\frac{\sum d^2 - n(\bar{d})^2}{n-1}} \tag{7}$$

$$\delta_{Er} = \frac{\delta}{\sqrt{n}} \tag{8}$$

$$t_{cal} = \frac{\bar{d}}{\delta_{Er}} \tag{9}$$

where $\bar{d}$ = mean difference from F_3 and F_1, Σd = summation of d, n = number of the observations, δ = standard deviation, δ_{Er}= standard error and t_{cal} = calculated value of t-test.

Table 1 Data extracted from Table 2 for the computation Paired t-test

(F_3)	(F_1)	$d = F_3 - F_1$	d^2
6.600	7.500	-0.900	0.8100
2.400	0.400	2.000	4.0000
54.460	32.000	22.460	504.4516
12.830	3.450	9.380	87.9844
20.200	16.400	3.600	12.9600
2.900	0.870	2.030	4.1209
41.000	25.430	15.570	242.4249
0.400	0.950	-0.550	0.3025
5.042	1.980	3.062	9.3758
2.079	0.000	2.079	7.7841
n = 10		**$\sum d = 58.731$**	**$\sum d^2 = 872.5944$**

$$\bar{d} = \frac{58.731}{10} = 5.8731 \tag{6}$$

$$\delta = \sqrt{\frac{872.5944 - 10(5.8731)^2}{10-1}} = 7.657 \tag{7}$$

$$\delta_{Er} = \frac{7.657}{\sqrt{10}} = 2.421 \tag{8}$$

$$t_{cal} = \frac{5.8731}{2.421} = 2.426 \tag{9}$$

Similarly, T_0 versus F_2, calculated value of t (t_{cal}) = 2.967

The table value of t (t_{Table}) is 2.262 at $\alpha \le 0.05$ and degree of freedom is 9. The calculated values of t were higher than the table value at $\alpha \le 0.05$ and degrees of freedom is 9. The effects of ceramic water filters (F_1 and F_2) were significant at $\alpha \le 0.05$.

3. Results and Discussion

The two ceramic water filters constructed in this study were presented in Figure 1. The ceramic filter labeled F_1 was produced with percentage composition of 40% sawdust and 60% kaolinite-clay but the ceramic filter labeled F_2 was produced with 50% sawdust and 50% kaolinite-clay. The connection of the two buckets with the ceramic filter in the upper bucket was presented in Figure 2. The appearance of the water (turbidity) after passing through the two filters (F_1 and F_2) and the raw water that was not filtered labeled as F_3 were snapped together and the pictorial view was shown in Figure 3.

The physical, chemical and biological properties of the water filtered through the ceramic water filter and the water that was filtered and the flow rate of water through the two filters were shown in Table 2. The filter 2 (F_2) with 50% sawdust and 50% kaolinite-clay had 108 ml/h while the filter 1 (F_1) with 40% sawdust and 60% kaolinite-clay had 77 ml/h. The means that the percentage composition of sawdust which is the combustible material influenced the porosity of the ceramic filter and F_2 with higher percentage of sawdust had higher flow rate than the F_1 with low percentage of sawdust of 40%. The result of flow rate in this study was in agreement with result obtained in this study that percentage composition of sawdust affects the flow rate of water through the ceramic filter [10, 11].

The two ceramic water filters reduced the turbidity, water hardness and the pH as shown in Table 2. This was in agreement with [7] that ceramic filter was adequate and effective for the removal of turbidity by 83 - 99%. The two filters reduced the concentrations of Calcium, Chloride, Magnesium, Iron and Zinc. [8] was in agreement with the result obtained in this study that ceramic water filter is effective for the removal of more than 90% iron from the water. The two ceramic filters reduced the concentration of Zinc below the limit that was above the permissible limit of Standard Organisation of Nigeria before filtration [18]. The ceramic water filter with 40% sawdust and 60% kaolinite-clay filtered or removed the concentrations of the chemicals analyzed better than the ceramic filter with 50% sawdust and 50% kaolinite-clay.

The ceramic water filters removed the total coliform after filtration as shown in Table 2. This was in agreement the study of [18] stated that ceramic water filter could remove bacteria by 98 - 100%. [9] also reported that ceramic water filter is effectively for removal of debris, parasites, chemicals and bacteria from the contaminated water thereby making the water safe for drinking. The ceramic water filter improved the turbidity and removed the microbial from the water and this was in agreement with the study of [19] that concluded that ceramic filter improved the turbidity and microbial quality of drinking water. The effect of passing the water through the two ceramic water filters 1 and 2 were significant on the quality of the water with calculated values of t-test were 2.426 and 2.967 for filter 1 and filter 2, respectfully and table value of t (t_{Table}) is 2.262 at $\alpha \leq 0.05$ and degree of freedom is 9.

Figure 1 Conical frustum-shaped ceramic water filter

Figure 2 Ceramic water filter put in the 15 litres bucket and connected to the storage tank

Figure 3 Appearance of the water after filtration through the ceramic water filters
F_1 = Water filtered through ceramic filter with 40%-60% (sawdust-clay)
F_2 = Water filtered through ceramic filter with 50%-50% (sawdust-clay)
F_3 = Raw water which was not passed through the filter

Table 2 Physical, chemical and biological properties of water before and after filtration

Parameters	Ceramic filter $_1$ (40% - 60%)	Ceramic filter $_2$ (50% - 50%)	Raw water	SON 2007	WHO 2011
Flow rate (mL/h)	77	108	-	-	-
Temperature (°C)	26.6	26.3	26.5	-	-
pH	7.50	7.10	6.60	6.5-8.5	6.5-8.5
Turbidity (NTU)	0.40	0.60	2.40	5	5
Hardness (mg/L)	32.00	42.00	54.46	150	150
Calcium (mg/L)	3.45	6.40	12.83	200	200
Chloride (mg/L)	16.40	16.90	20.20	250	-
Iron (mg/L)	0.87	1.03	2.90	0.30	-
Magnesium (mg/L)	25.43	35.58	41.00	20.00	20.00
Manganese (mg/L)	0.950	0.850	0.400	0.200	0.400
Zinc (mg/L)	1.980	2.756	5.042	3.000	-
E. Coli (cfu/100mL)	ND	ND	ND	0	0
Total coliform (cfu/100mL)	ND	ND	2.08	10.00	10.00

ND = Not detectable
SON = Standard Organisation of Nigeria, WHO = World Health Organisation

4. Conclusion

The two ceramic water filters were constructed using kaolinite-clay and sawdust with percentage composition of sawdust to kaolinite-clay by volume were 50%-60% and 50%-50%. The flow rates of the ceramic filters for 50%-60% and 50%-50% sawdust to kaolinite-clay composition were 77 and 108 ml, respectively. The filters removed total coliform from the water after filtration

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