Network for Research and Development in Africa
International Journal of Knowledge and Dynamic Systems
ISSN: 2384-5368, Volume 13, Issue 6
PP 11-21 (October, 2023)
DOI: 6732-1453-71-1362
arcnjournals@gmail.com
https://arcnjournals.org

CERAMIC WATER FILTER AS POINT OF USE (POU) WATER TREATMENT TECHNOLOGY FOR THE TREATMENT OF RIVER WATER IN MAIDUGURI, BORNO STATE

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***Abstract**: The alarming state of safe water deprivation among rural communities in Nigeria is well recognized and requires urgent attention. This study produced Ceramic Water Filters (CWF) as point-of-use (POU) water treatment technology. The CWFs were produced from locally available combustible materials namely; maize husk with clay and grog. The clay sample was evaluated and tested for plasticity, linear shrinkage, firing shrinkage, total shrinkage and water absorption. The results show that the clay as it fell within limit for linear shrinkage of 12.3% , any value > 15% will warp or crack. Combustible material and grog do not have significant moisture to affect the final mix (2.6g). A successful mix of 75% clay and 25% combustible material and grog, having a ratio of 6:1:1 respectively was achieved while other mix ratio of above 25% of combustible material slumped. Filtering test was carried out on each of the 650 ^{0}C and 900 ^{0}C. The raw water sample of the following physio-chemical parameters were Turbidity 81 NTU,Nitrate 29 mg/l, Phosphate 0.26 mg/l, TDS 240 mg/l, Alkalinity 131.53 mg/l, EC 1800, pH 8.5 and Color 16.40. The filtered water samples of the aforementioned parameters were World Health Organisation (WHO) compliant with the following recorded values of the 650^{0}C pots- Turbidity 3 NTU,Nitrate 1.3 mg/l, Phosphate ND, TDS 31 mg/l, Alkalinity 20.36 mg/l, EC 74, pH 8.3 and Color 1.23. The 900^{0}C pots- Turbidity 0 NTU,Nitrate 1.1 mg/l, Phosphate ND, TDS 27 mg/l, Alkalinity 20.40 mg/l, EC 69, pH 7.1 and Color 1.2. flow rate of CWFs fired at 650 ^{o}C have shown increased flow-rate of 83.8 ml/h than the 900 ^{o}C CWFs at 60.2 ml/h. The flow rate of the CWF produced by the 650^{0}C was though more effective, but not as effective the one produced at 900^{0}C in physico-chemical and microbial removal efficiency. The initial concentrations of faecal coliform and E. coli, were 189 × 10^3 Cfu and 43 × 10^3 Cfu respectively. Recorded values fell within low risk category having 0-1 for the 900 ^{0}C pots, the least removal efficiency registered 74.1 % for total coliform and a higher value of 95.8 % for E.coli and 100 % for faecal coliform. The 650 ^{0}C ranged between 0-2 Cfu, least removal efficiency registered 63.0 % Total coliform, both Faecal coliform and E.coli recorded values between 83.3 % to 100 %.*

***Keyword**: Ceramic Water Filter, Maize Husk, Nitrate, Phosphate, Maize Husk, Saw dust.*

1.0 Introduction

Waterborne diseases are very rampantin sub-Saharan Africa and other developing countries due to lack of access to clean water and poor sanitation (Ohnyekachi et al, 2020). For many rural communities in developing countries, unreliable access to safe drinking water remains an issue of great concern (Richard, 2021).

The United Nations, coordinated by UN-Water has developed SDG-6 Global Acceleration Framework which aimis to ensure the availability and sustainable management of water. The SDG-6 has identified five accelerators to achieve this aim among which is Innovation (WHO, 2022). In pursuit to proving safe drinking water to those in need, Point-of-use (POU), household water technology (HWTs) are innovations that emerged as a complimentary solution to the centralized water supply systems. I n an effort to combart this problem, Centre for Disease Control and Prevention (CDC) has identified four HWTs methods that have been proven to reduce diarrhea incidences in use; chlorination, solar disinfection, flocculation/sedimentation, and ceramic filtration (CDC, 2021). HWTs and safe storage interventions are proven to improve water quality and reduce diarrhea disease incidence in developing countries (WHO, 2022).Interestingly, one of such HWT that is feasible in Nigeria is the production of Ceramic water filters (CWFs). CWFs has become instrumental in purifying water particularly in countries with limited access to safe drinking water, (Komba et al, 2022).CWFs are used in form of intervention. Reportedly, over 30 filter factories across the globe, examples of such factories can be found in Cambodia, Vietnam, India, Ghana, Nigeria, Kenya, to name a few. Almost all are operating on similar principles and methods (Agbo et al, 2015). Thus, manufacturing methods employed must meet local circumstances and locally available materials. CWFs fabricated from local materials and manufactured locally are one of the acceptable POU ater treatment techniques which improve drinking water quality by removal of microbes and reducing the chemical and turbidity content of the sourced water at household level (Haiyan *et al*., 2020).

Access to safe water is a great problem faced by the average Nigerian, which has resulted in transmission of different waterborne diseases, especially cholera. The use of CWF has been found useful and effective to address this problem in some local government areas in Borno State. According to the weekly cholera situation report prepared by the Borno State Ministry of Health, as of 10 December, 2017, cholera outbreak had claimed the lives of at least 61 individuals in Borno state. Cholera have been reported in no fewer than 15 locations in an IDP camp, with approximately 20,000 in Jere local Government (WHO, 2017). An assessment of the situation revealed mode of transmission for cholera was household transmission (40%), where in most cases children were taking care of their younger siblings and continuing to have normal contact with household members showing symptoms of cholera without use of appropriate hygiene practices. The second mode of transmission was found to be from public places (17%); followed by transmission through water sources (15%); transmission specific to an area or specific group (14%); transmission at health centers (10%) and funeral rituals (4%). These findings informed UNICEF and its partners to plan for WASH interventions in the affected settlements (UNICEF, 2017). Interventions in the form of bucket chlorination using Calcium Hypochlorite (HTH chlorine) solution, and disseminating proper hygiene information to IDPs was organised. CWF were not widely used in theses instances. This study focuses on developing a filter to assist in reducing the periodic incidence of waterborne diseases in rural areas of Borno State, Nigeria.

Therefore the aim of this study was to develop a CWF using local materials and different firing temperature and mixing ratio in improving the quality of drinking water for household water treatment.

2.0 Materials and Methods

2.1 Materials

The materials used in this study include clay, maize husks, grog ,sack, bricks, mortar and pestle, hammer, weighing machine, 600 µm Sieve, Polythene bags, Cans, Oven, 5-liter jerry cans, masking tape, measuring cylinder, marker, milling machine, ruler, disposable gloves, recording sheets.

2.2 Sample Collection and preparation

The raw materials used for the production of the CWFs were Maize husks, Grog (burnt and broken ceramic pots), water and Clay. The Clay sample was obtained from Mandarari village in Konduga L.G.A of Borno State, which was dug at a depth of 0.4m and then collected in a sack and transported to Maiduguri pending preparation and analysis. The grog was obtained from local pot sellers and the maize husks from the grain market in Gamboru. Grog and maize were obtained in Maiduguri, Borno State, Nigeria.

The clay was dried and spread on a sack.T~~t~~he sack was weighed down using bricks in order to hold it in an undisturbed position. The clay was then broken into smaller pieces using hammer. The clay and grog were taken to the Ramat Polytechnic Laboratory for grinding using mortar and pestle. Thereafter, both the grog and clay was sieved through a 600µm sieve size and weighed on a weighing machine. The clay and grog were then packaged in polythene bags, each containing 500g sieved clay and 5g sieved grog. A total of 17 packaged bags were obtained for the clay and 21 for the grog. The maize husks were accessed for any foreign particle before it was grinded in the milling machine. 600µm sieve was used to sieve the maize husks and weighed, 5g each and packaged in polythene bag.

2.3 Raw Material Evaluation

Raw materials were evaluated to know their characteristics and behavior. Analysis and procedures for the raw material evaluation were adopted from the Ceramics Manufacturing Working Group (2011).

i. Test for Water of Plasticity

One of the packaged 500 grams of clay was used for this test. The clay was kneaded by adding more water until the clay is a smooth having the right consistency for moulding which was 150ml.The amount of water of plasticity was calculated using the following formula:

$$Percent\ water\ of\ plasticity = \frac{Weigh\ \ of\ water}{Weigh\ \ of\ dry\ clay}\ \mathrm{X}\ 100$$

ii) Dry Shrinkage

From the well-kneaded mass of clay used for calculating water of plasticity above, 9 bars were produced that are 14 cm long, 4 cm wide and about 1 cm thick. On the face of each bar a sharp scratch exactly 10 cm long was drawn. The bars were allowed to dry slowly and evenly; turning them as needed to prevent warping. Once the bars were dried, the length of the scratch was re measured. The dry shrinkage was determined using the following equation:

$$\boldsymbol{Percentage\ Linear\ shrinkage} = \frac{Plastic\ Length - Dr\ \ \ Length}{Plastic\ Length}\ \mathrm{X}\ 100$$

(iii) Firing Shrinkage

Firing shrinkage was usually determined on samples that have been fired to several different temperatures (250°C, 650°C, and 900°C), following the standard firing schedule. Each bar made for the previous test was marked with a test firing temperature of 250°C, 650°C and

950°C. The bars were transported to Bayero University Kano for the firing.The dried bars were fired, three bars were fired to each test temperature. The length of the scratch on the fired bar was measured after firing. The firing shrinkage was calculated using the following equation:

$$\textbf{Percentage Firing shrinkage} = \frac{Dry\ Length - Fire\ \ Length}{Dry\ Leng}\ \text{X}\ 100$$

(iv) Total Shrinkage

Total shrinkage is how much the clay or filter mixture shrinks from its plastic state to its fired state and was calculated using the following equation:

$$\textbf{Percentage Linear shrinkage} = \frac{Plastic\ Length - Fire\ \ Length}{Plastic\ Length}\ \text{X}\ 100$$

2.4Filter Production Process

1500g of sieved clay were poured into a basin together with 150g of maize husks and 50g of grog. Water was then added gradually (100ml was added at a time) the final water content for the mix was 550ml.It was then mixed manually until a homogenous and workable consistency is achieved. It forms a relatively dry but cohesive mixture which is then moulded to form the filter shape. Although ratios of clay to sawdust of 50:50 and 40:60 have been used efficiently Akosile et al., (2020), effort to increase the combustible material greater than 25% was unsuccessful as it slumped.

Table 2.4 Combinations Used for Trial Testing

Quantity Of Filters 12	Dry Powdered Clay Mass (g)	Dry Powdered Maize Husk (g)	Dry Powdered Grog (g)	Total Mass (g)	Approx. Water Used (ml)
3	1000	1000	1000	3000	670
3	1000	500	500	2000	610
3	1000	500	250	1750	550
3	1500	250	250	2000	550

10 pots were moulded and allowed to dry gradually in the shade to avoid crack. After being sufficiently dry, hard enough to be transferred to the sun which was approximately 3 hours (drying time). It was left to dry 72 hours more to allow for proper packaging without causing damage to the pots.The pots were then properly packaged and sent to Bayero University Kano, Mechanical Engineering Laboratory for firing. Temperature used for firing the pots were 250 ^{0}C ,650 ^{0}C and 900 ^{0}C.

Figure 3.6: Sample of fired CWF firing

Figure 3.7: Sample of damaged CWF after

At the end of this stage 7 filter pots were successful, which were from the 650 ^{0}C and 900 . ^{0}C pots. The samples were then subjected to test for flowrate.
Finally the effectiveness of the filters were determined by carrying out physio-chemical and microbial tests on the raw and treated water samples. A five (5) liter Jerry was used to collect raw water sample from River Ngadda at 4 different locations namely - Fori Bridge, Lagos Street Bridge, behind milk shop under the by-pass bridge and Moro-Moro bridge. The container was labelled for physical, chemical and bacteriological analysis following procedure by The District Laboratory Practice in Tropical Areas (2006).
The raw water samples were passed through the filters and the filtered water collected through a plastic receptacle covered with a lid to obtain the filtered water samples. The filtered water was taken to the laboratory in plastic bottles. The raw and the filtered water samples were then tested for the following parameters; microbial load counts (*total coliform, faecal coliform and E.coli*) and physio-chemical parameters (colour, pH, turbidity, Total Dissolved Solids (TDS), phosphate, nitrate and alkalinity) using standard laboratory procedure.

3. Results and Discussion

Physio-chemical Analysis

a. Turbidity

Table 3.1 show turbidity tests result for the four samples, for this parameter the WHO standard for turbidity is 5 NTU. Highest value recorded from the four samples was 81.0 NTU from Moro moro the vegetable market where human activity and refuse dumping especially of the perishables is being consistently practiced. The CWFs show a high reduction of turbidity to below the WHO standard, as can be seen in the 900 ^{0}C . Hence this shows that the higher the firing temperature of the pots the more removal effectiveness of the pots
(Zeraffe and Bekalo,2017) as the value for the 650 ^{0}C pots ranged between 1.3 NTU-2.1 NTU while that of the 900 ^{0}C ranged between 0-0.2 NTU.

Table 3.1: Raw and filtered values for Turbidity of the four samples

Turbidity (5 NTU)-WHO standard							
Locations	Raw	Cf1-650	Cf2-650	Cf3-650	Cf4-900	Cf5-900	Cf6-900
Fori	40.10	1.62	1.80	1.30	0	0	0
Lagos St	58.90	1.8	2.1	1.90.2	0.2	0	0.1
Milk Shop	60.03	1.9	2.0	1.8	0	0	0.1
Moro m.	81.0	4.4	5.7	3.9	0.1	0	0

b. TDS

Another parameter was the total dissolved solutes (TDS); which provides a rough indication of the overall suitability of water for various purposes (H.D Chung *et al.*,)For this parameter, the WHO standard for TDS in drinking water is 250 mg/l and the value for the raw water falls below the WHO standard, hence the CWFs were effective in reducing the TDS from an initial high value from the four raw water samples of 240 mg/l to 203 mg/l.

Table 3.2: Raw and filtered values for TDS of the four samples

TDS (mg/l)							
Locations	Raw	Cf1-650	Cf2-650	Cf3-650	Cf4-900	Cf5-900	Cf6-900
Fori	60	55	55	50	47	45	47
Lagos St	62	30	32	31	28	27	28
Milk Shop	63	41	44	42	33	32	32
Moro m.	240	225	225	220	206	202	203

c. Nitrate

Presence of nitrate in drinking water is largely due to application of inorganic fertilizer and animal manure in agricultural areas (M. H. Ward et al.,). This can be seen in Table 3.3 the high nitrate content in the raw water sample of Fori (29 mg/l), activites around the water source include animal rearing and small scale agricultural practices. Thus the pots were effective in reducing the value to below the acceptable limit of 10 mg/l to 2.74 mg/l. Values from the remaining raw water samples were also reduced.

Table 3.3: Raw and filtered values for Nitrate of the four samples

Nitrate (mg/l)							
Locations	Raw	Cf1-650	Cf2-650	Cf3-650	Cf4-900	Cf5-900	Cf6-900
Fori	29	2.93	2.94	2.94	2.73	2.70	2.74
Lagos St	1.39	1.26	1.29	1.27	1.23	1.21	1.24
Milk Shop	1.36	1.30	1.31	1.31	1.26	1.24	1.24
Moro m.	1.54	1.30	1.32	1.31	1.21	1.10	1.10

d. Phosphate

The result of this study revealed that the CWFs had good removal efficiency of phosphate as can be observed from Table 3.4. The phosphate value for the raw water sample from Fori was relatively high (29 µg /l) and it was not detected after filteration in all the CWFs. There was also a significant decrease in the remaining four samples which ranged between 0.01-0.04 µg/l.

Table 3.4 Raw and filtered values for Phosphate of the four samples

Phosphate (µg/l)							
Locations	Raw	Cf1-650	Cf2-650	Cf3-650	Cf4-900	Cf5-900	Cf6-900
Fori	0.26	ND	ND	ND	ND	ND	ND
Lagos St	0.15	0.03	0.04	0.03	0.02	0.02	0.02
Milk Shop	0.1	0.01	0.02	0.01	0.01	0.01	0.01
Moro m.	0.09	0.03	0.04	0.04	0.02	0.02	0.03

e. Alkalinity

The alkalinity decreases considerably in all the CWFs as can be observed in Table 3.5 with an initial value of 103.52 mg/l to minimum of 20.36 mg/l of the Fori sample water. The lower decrease can be observed in the remaining three locations, with initial values of 115.94 mg/l,127.42 mg/l, and 131.53 mg/l to 111.2 mg/l, 113.6 mg/l and 111.2 mg/l respectively for 650 ^{0}C, and 109.32 mg/l, 113.08 mg/l and 109.8 mg/l for the 900 ^{0}C. This might be due to the scrubbing adopted in the subsequent filtering which had lead to increased flow thereby allowing ions to pass through. In comparison the 900 ^{0}C outperformed the 650 ^{0}C in removal efficiency in the above mentioned parameters. Thus it should be noted that the raw water samples falls below the permissible limit for Alkalinity of 600 mg/l.

Table 3.5 Raw and filtered values for Alkalinity of the four samples

Alkalinity (mg/l)							
Locations	Raw	Cf1-650	Cf2-650	Cf3-650	Cf4-900	Cf5-900	Cf6-900
Fori	103.52	20.36	24.41	24	22.5	20.4	20.41
Lagos St	115.94	111.2	111.39	111.31	109.49	109.33	109.32
Milk Shop	127.42	123.15	123.23	122.9	113.6	113.08	113.42
Moro m.	131.53	111.2	114.12	112.9	110.8	109.8	110.6

f. Electrical Conductivity (EC)

The permissible limit in drinking water is 1500 µS/cm. The level of EC of the water before filtration were 101 µS, 190 µS, 210 µS and 1800 µS. A reduction of electrical conductivity can be seen in Table 3.6 of the highest value above the permissible limit from 1800 µS/cm to a lower value of 601 µS/cm. EC is related to the amount of ions present in a solution (Adhena et al. 2015). Lower values from the samples indicate a decreased amount of salts present in the raw water samples. The results also show a similar behaviour from the 900 ^{0}C pots with filtered value of 20.41 µS/cm outperforming the 650 ^{0}C having filtered of 1121.2 µS/cm.

Table 3.6 Raw and filtered values for Electrical Conductivity (EC) of the four samples

EC							
Locations	Raw	Cf1-650	Cf2-650	Cf3-650	Cf4-900	Cf5-900	Cf6-900
Fori	101	74	78	75	70	69	69
Lagos St	190	168	169	167	150	150	151
Milk Shop	210	196	201	197	170	166	168
Moro m.	1800	712	720	716	604	601	604

Flow rates of the CWFs of the four samples

The CWFs capacity ranged between 730 ml to 955 ml. CWFs burnt at lower temperature have increased flow-rate and low removal efficiency than those fired at high temperature (De Jonghe & Rahaman, 2003). This can be observed in figure 4.9 below where the flow rate of CWFs fired at 650 ^{o}C have shown increased flow-rate of 83.8 ml/h than the 900 ^{o}C CWFs at 60.2 ml/h. The flow-rate of the CWFs ranged between 60.2-83.8 ml/h. Lower flowrates in higher temperature sintered pots are due to smaller pores as compared to the 650 ^{o}C having increased flow-rate due to larger pores.

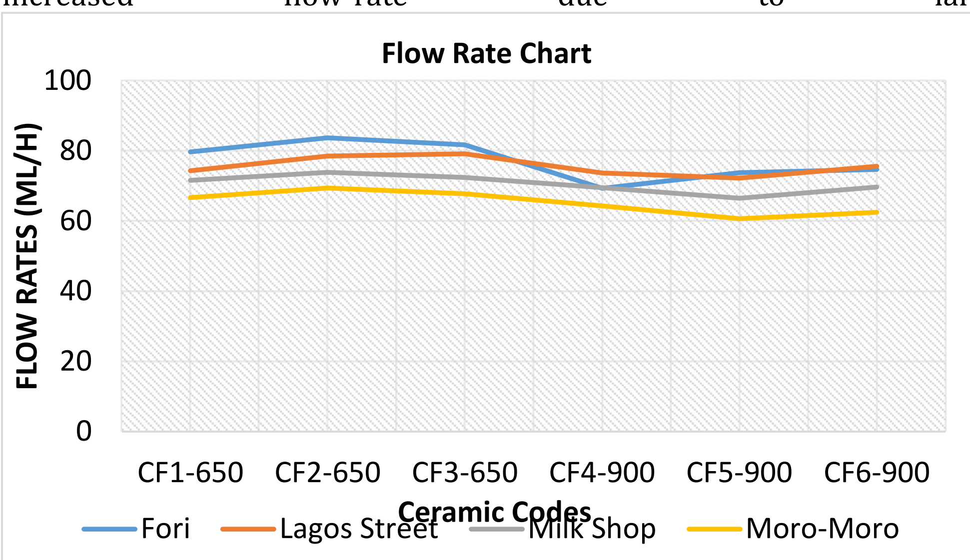


Figure 4.5 Flowrates of the CWFs of the four samples

Microbial Analysis

The initial concentrations of *faecal coliform*,*total coliform* and *E. coli,* were 90 × 10^3 ,189 × 10^3 Cfu and 43 × 10^3 Cfu respectively. The result of the filtered sample were presented in Fig 1 and 2.

Removal Efficiency of the 650 ℃ CWFs

The microbial removal efficiency from the 650°C CWFs of the four location sites ranged between 63.0 % to 100%. As it can be seen from Fig. 1, the least removal efficiency registered 63.0 % *Total coliform*, both *faecal coliform* and *E.coli* recorded values between 83.3 % to 100 %.

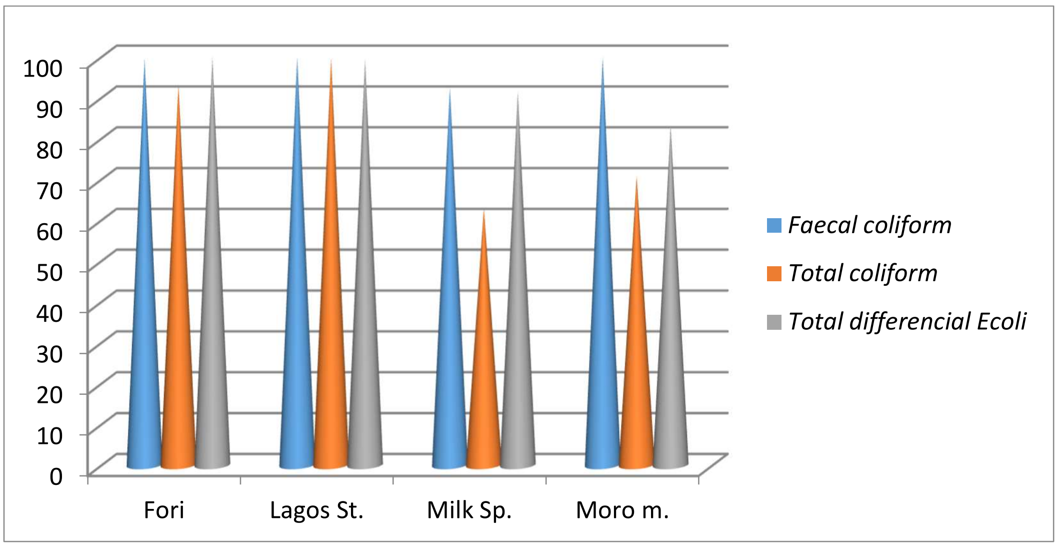
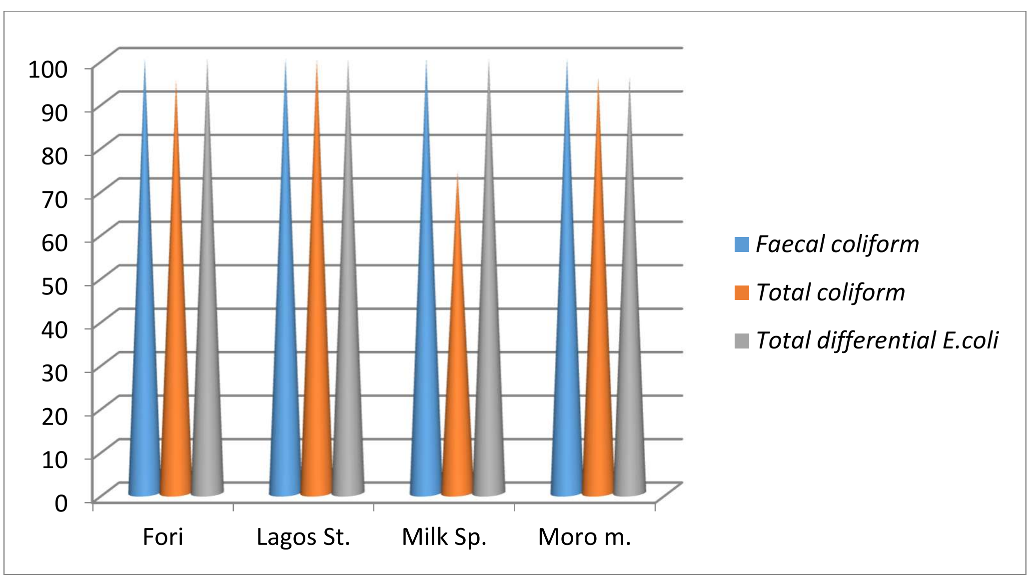
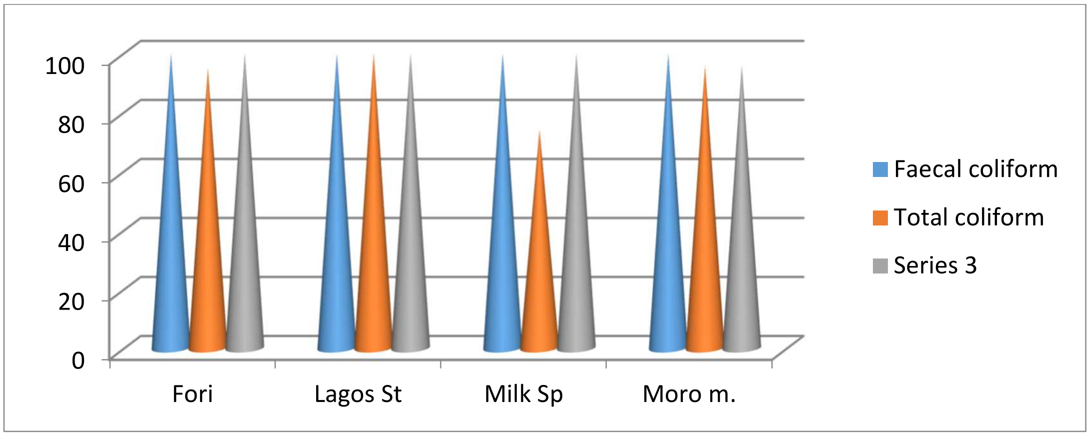


Figure 1: **Removal Efficiency of the 650 ℃ CWFs**



Removal Efficiency of the 900 ℃ CWFs

Also the result of this study showed that the microbial removal efficiency increases with increase in sintering temperature. The least removal efficiency registered 74.1 % for *total coliform* and a higher value of 95.8 % for *E.coli* and 100 % for *faecal coliform*. This is most likely obtained due to vitrification of the CWFs at higher sintering temperature,this is in agreement with what is reported by Zereffa and Desalegn (2019) with a similar missed ratio of 70:30 fired at 900 °C. The results were depicted in Fig. 2.



Removal Efficiency of the 900 ℃ CWFs

4.0 Conclusion and Recommendation

Rural communities in Borno State are faced with several challenges associated with access to clean drinking water especially in the rainy season. To remedy this problem, a CWF was produced to treat contaminated water from different sources to provide access to clean water supply to these communities. In this study, it was observed that household water technology such as CWF provides some potentially viable solutions to provide clean drinking water. Additionally, it is an effective alternative used as a POU water treatment technology which was able to improve both bacteriological and physical qualities of the water. Thus, because CWF was produced from locally available materials, it could be a viable option for rural areas to have access to good drinking water for their domestic use. It is recommended that CWF should be adopted by local communities as a POU water treatment technology especially where conventional water treatment is absent.

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