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INVESTIGATION OF THE FEASIBILITY OF ALTERNATIVE BURNOUT MATERIAL (MAIZE COB) VERSUS THE TRADITIONAL MATERIAL (SAWDUST) FOR POINT-OF- USE CERAMIC WATER FILTER PRODUCTION

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Abstract

Ceramic water filters, are a promising household water treatment technology. Filters were produced using clay as the base material and two locally available burnout materials (sawdust and maize cob). The clay which was classified as an Inorganic clay of low to medium plasticity has a liquid limit of 41.1% and plasticity index of 37.4%. The sizes of the combustible materials are 5,10, 22 microns mixed in proportions of 1:1 and 1:2 by proportions of clay and burnout materials respectively, moulded and fired to a temperature of 1000°C. In the end, ten filters were produced from various particles sizes and proportions of the sawdust and maize cob. The bulk density of the filters ranged from 1.67 to 3.5 g/cm^3 with a typical value of 2.63±0.57 g/cm^3. Apparent porosity ranged from 94.94 to 99.87% with a typical value of 99.10±1.13%; while water absorption varied from 28.6 to 59.71 % with a mean of 40.02±9.49 %. Flow rate ranged from very slow rate of 0.051 to 0.92 L/h with a typical value of 0.354±0.226 L/h. Based on type of burnout material, filters made with sawdust had higher flow rates (0.433 L/hr) than those made from maize cob (0.291 L/hr). The percent turbidity removal ranged from 9.1% - 43.7% on the first week to 30.6 – 70.4% on the fifth week of the test for filters made from maize cob; whereas the percent turbidity removal ranged from 5.7 – 35.3% on the first week to 44.9 – 75.6% on the fifth day for sawdust. Filters made from sawdust performed significantly better than those made from maize cob ($p = 0.044$) at 95% confidence level. In terms of particle size, there was an increase in efficiency of Coliform removal efficiency from 99.6 to 99.8% as the particle size of burnout materials increased from 5 µm to 22 µm. Filters made with lower proportion (1:1) of burnout materials exhibited higher Coliform removal (99.76%) than those made with higher (2:1) proportion (99.63%). However, the proportion of burnout materials within the range used in this study did not significantly affect percentage Coliform removal ($p = 0.247$). Filters made from sawdust generally performed better than those made from maize cob.

1.0 INTRODUCTION

Water is among the basic requirements required to sustain life on earth. Its use spans to various aspects of human life, from agriculture to household use as well as industries/factories etc. WHO/UNICEF joint monitoring program, described improved sources of water as water obtained from piped network of water delivery, tube or dug wells, springs and rainfall. According to a report from World Health Organization, in 2015 up to 663 million individuals which translates to approximately 1/10th of the global population had no access to improved/safe drinking water, in the same year 2.4billion individuals which is 1/3rd of the global population lacked proper sanitation

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[1]. Diarrheal diseases caused by exposure to drinking water contaminated with faecal matter has been fingered as the second largest leading cause of mortality in children below the age of 5. [2]. Contamination of drinking water sources due to natural and anthropogenic causes is a leading cause of potable water scarcity and general water stress being experienced in several parts of the world. The situation is even more severe among the disadvantaged section of the society, particularly those living in rural areas, urban slums, correctional facilities and internally displaced persons' camps.

The probability of consumption of contaminated water in such places on a regular basis is predictably high. In many rural areas, streams and rivers that were once pristine and served as reliable drinking water sources for the people have become a mere conduit for conveyance of wastewaters of both domestic and industrial origins. Moreso, there are no cheap and readily available point-of-use treatment methods at the disposal of persons living in the highlighted places for purifying contaminated water from local sources before consumption. However, ceramic filters made from clay and organic burnout waste materials have emerged as an adaptable and promising solution to mitigate the problem of water contamination among the disadvantaged members of the global society [3, 4]. This is because, the unit can be made entirely from cheap and locally available materials such as clay and waste organic materials.

In order to achieve cost effectiveness and high performance efficiency, there is a need for quality control and to optimize the process and parameters such as clay properties, combustible material, firing temperature, additives, pressure [5]. Studies have reported a wide variation in quality control protocol of over fifty ceramic water filter factories situated in the same locality and a strong indication that each even filters produced by the same factory can present discrepant peformances [6]. Yang et al [7] highlighted two major critical parameters that determine the performance of ceramic water filters namely, manufacturing process (raw material selection, firing temperature and biocide impregnation) and raw water quality. Studies in various developing countries have given strong indications that the spate of mortality and morbidity associated with ingestion of contaminated water can be checked by the use of point-of-use ceramic filters made of locally available materials. Classen et al. [8] reported 70% general reduction in diarrheal risk in Bolivian households provided with these filters and 83% in risk reduction for children below five years old. With use of this simple, low cost and renewable technology, low-income households can be guaranteed of microbiologically safe drinking water [9,10]. However, studies in rural China have reported some discrepancies between laboratory performance of ceramic water filters and field performance due to poor quality control by users usually introduce contaminants into the system [11].

The functionality of the ceramic water filter is enhanced by the integration of burn-out materials which are basically combustible organic materials which leave a system of pores in the filter after firing to enhance hydraulic properties. Besides, these burnout materials leave mineral deposits in the filter pores that serve as chemically active sites for adsorption and ion exchange. A wide range of burnout materials have been successfully used for the production of ceramic point of use water filters at laboratory scales. Apart from using locally available materials, one of the strongest attractions of ceramic filters is that materials used to generate burnout pores are usually waste-derived, which means that they can be sourced free of charge or at minimal cost. While sawdust has been the most commonly used burnout material with good results [12, 13, 14], several recent studies have investigated the feasibility and efficiency of other waste materials. Yang et al successfully tested the efficiency of ceramic filters using waste paper and leaves as burnout materials [7]. A few studies used sawdust in the place of sawdust as a burnout material but the result was marred by poor hydraulics because the process was not properly controlled to optimize porosity [15]. Researchers have also found that further refinements to the technology can be achieved by the use of additive biocides such as Silver Nitrate and Lanthanum (III) [16, 17].

Despite the poor access of potable water in many parts of Nigeria, the application of point of use ceramic water filters is still very scanty. Likewise, very few studies have been conducted in the country to standardize the production process or even investigate the applicability and efficiency of the technology. On the contrary, reports of widespread application and innovation in other developing countries like Benin Republic, Kenya, and Cambodia abound [12, 14, 18]. Although some studies have been carried out in the area of ceramic filters in Nigeria but these studies have not been able to translate to its accessibility in the Nigerian markets. Besides, there are several organic waste materials that have not been tested for applicability in the production of ceramic water filters. One abundantly available organic waste materials that presents a promising potential to serve as a burnout material for ceramic water filter is maize cob.

Nigerian produces over twelve million metric tons of maize annually and each maize ear generates one maize cob waste that must either be disposed on landfills or incarnated. Hence this study was aimed at investigating the applicability of maize cobs as burnout materials for ceramic water filters and to compare the performance with filters made with sawdust in terms of physical properties, flow rate and efficiency of water treatment.

2.0 MATERIALS AND METHOD

2.1 Materials

Mazie cobs and sawdust were readily obtained from Nsukka as waste agricultural and timber wastes respectively. Clay was also obtained from Nsukka, dried and ground into powders and sifted at the point of collection before it was moved to the laboratory. The clay was sifted to a size of 1micron using a mosquito net. The combustible materials that is the sawdust and maize cob were collected from timber shed in Nsukka metropolis while the latter, maize cob was gathered from the farms. The three materials were sun-dried first, then oven dried to ensure they were completely devoid of any form of moisture and then finally ground before they were individually transferred to a sieve shaker with a stack of sieve sizes of 5,10 and 22µm and sieved. 6kg of clay was measured out and mixed with different sizes of burnout materials sieved from the sieve shaker. Each of the particle sizes (5,10 and 22µm) of each burnout material (maize cob and sawdust) were mixed individually with the clay in the ratios of 1:1 and 1:2 as shown in Table 1, giving twelve individually unique filters. As soon as the dry raw materials were thoroughly mixed, water was added gradually and mixed thoroughly to facilitate workability.

The mixture was kneaded to drive off all the air present in the mixture by folding and pressing. After the kneading process, a consistent, air free mixture of clay and the combustible material was produced and then moulded into the desired shape. The mix was then pressed into a plastic bowl to produce the desired shape of the pot by hand moulding and then left in the open air to dry for four days before being transferred to the kiln for firing. The pots were then arranged in the kiln and fired gradually and slowly firstly to a 100˚C for the first two hours to enable the moisture still contained in the pots to evaporate. After the boiling off of the moisture contained in the pots at 100˚C, the temperature was increased gradually until up to 1000˚C and held for several hours for the pots to properly cook after which it was allowed to cool in the kiln for another 24 hours till it was cold enough to be handled by hand without damaging. The process has been succinctly captured in Figures 1 and 2.

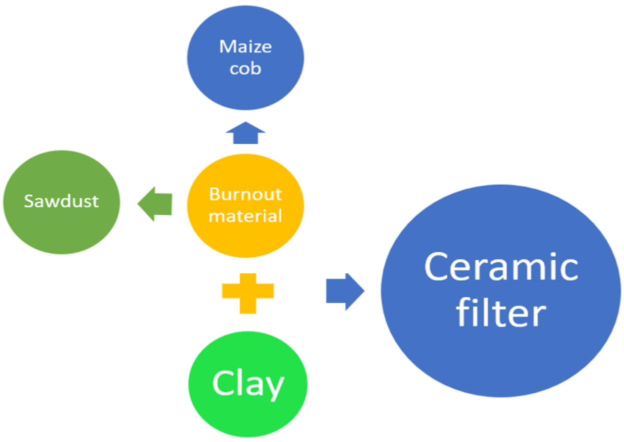

Figure 1: Ceramic filter process

Table 1: Details of ceramic filter materials and characteristics

Designation	Burnout Material	Particle Size	Proportion of burnout material	Proportion of clay	Bulk density	Apparent Porosity %	Water absorption %
M1	Maize cob	5 µm	1	1	3.2640	99.88	30.53
M2	Maize cob	10 µm	1	1	3.1787	99.54	31.46
M3	Maize cob	22 µm	1	1	2.5332	98.70	39.48
M4	Maize cob	5 µm	2	1			
M5	Maize cob	10 µm	2	1	2.5228	99.87	39.63
M6	Maize cob	22 µm	2	1	2.1683	99.67	46.12
S1	Sawdust	5 µm	1	1	3.4934	99.80	28.60
S2	Sawdust	10 µm	1	1	3.1819	99.50	31.43
S3	Sawdust	22 µm	1	1	1.6702	98.79	59.37
S4	Sawdust	5 µm	2	1			
S5	Sawdust	10 µm	2	1	1.9536	99.72	51.18
S6	Sawdust	22 µm	2	1	1.6712	98.80	59.71

The filters were characterized for water absorption, bulk density and porosity in accordance with ASTM C373-88, 2006 standard test methods for refractory bricks and shapes. To ascertain the hydraulic efficiency and feasibility of the filters, flow test was performed using low turbidity water samples (rain water and well water) to reduce the incidence of clogging on the pores of the filters. The ceramic filter was first soaked in water for a minimum of 24 hours before the test was conducted in other to remove traces

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of ashes resulting from the burn off of the combustible material. The filter were then assembled inside receptacle and the water samples were poured into them. The quantity of filtrate produced over intervals of time was measured and then used to estimate the flow rates. The water samples were tested for pH, turbidity and total coliforms before and after filtration. Throughout the duration of the testing period, each of the filters were filled with water twice daily. The influent water was collected daily from the rainwater storage tank and a well prior to treatment. The microbial indicators in the influent and effluent water samples were analysed using membrane filtration technique using 0.45 mm diameter pore size membrane filter. Turbidity of influent and effluent water samples were tested using a turbidimeter and the pH was measured using a pocket size pH meter model HI9610. Filtration rates of the pots were measured as a function of the grain size and proportion of the combustible material used. Results obtained were subjected to descriptive and exploratory statistical analyses. Multiple factor analysis of variance (ANOVA) was employed to ascertain the effects of particle size, type of burnout material and proportion of burnout material on the properties and performance of the filters.

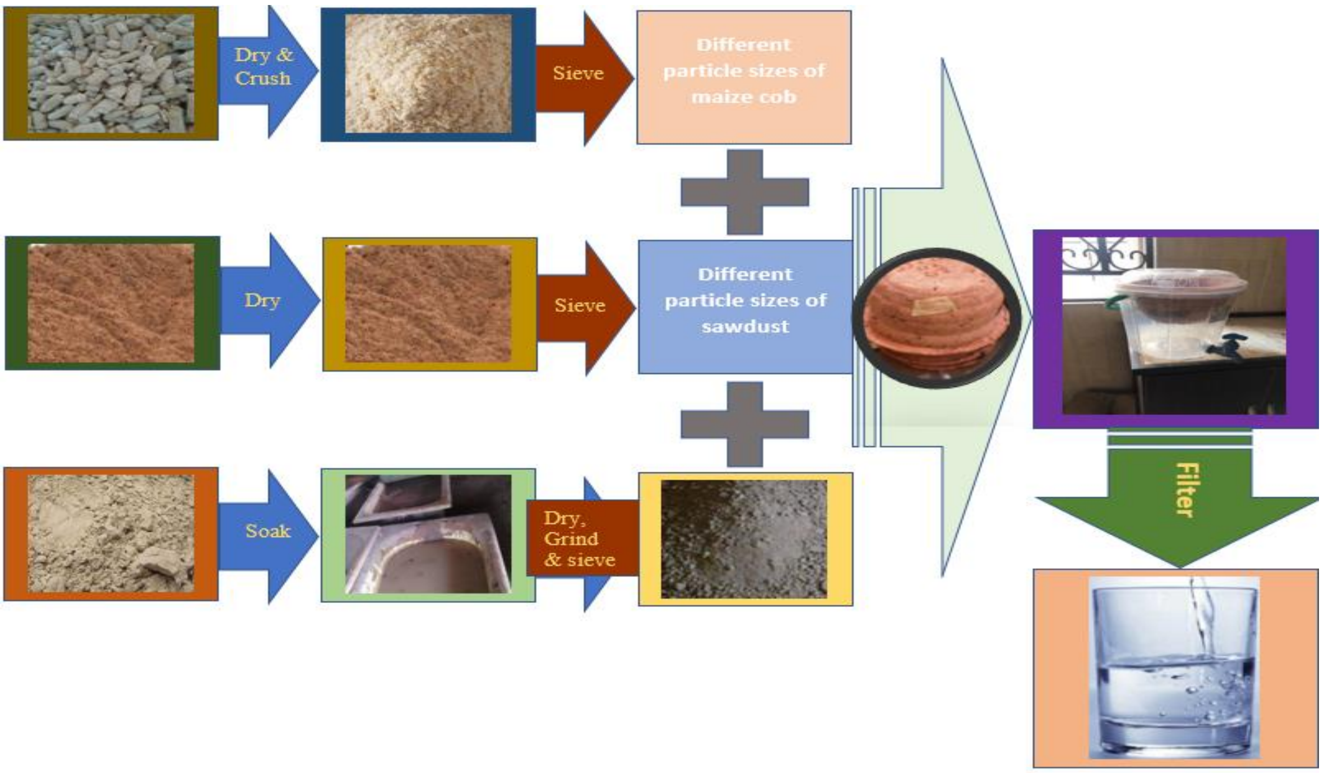


Figure 2: Process flow chart for ceramic filter

3.0 RESULTS AND DISCUSSIONS

3.1 Physical Characteristics of the Ceramic Filters

From the results obtained (Figure 3), the clay after being subjected to Atterberg limit tests, the liquid limit obtained was 41.1% with a Plastic limit of 37.8%. The soil is classified as an organic clay with low to medium plasticity and a Plasticity index of 37.4%. The bulk density of the filters ranged from 1.67 to 3.5g/cm^3 with a typical value of 2.63±0.57g/cm^3. Apparent porosity ranged from 94.94 to 99.87% with a typical value of 99.10±1.13%; while water absorption varied from 28.6 to 59.71% with a mean of 40.02±9.49%. Flow rate ranged from very slow rate of 0.051 to 0.92L/h with a typical value of 0.354±0.226 L/h. The physical properties of the filters were generally affected by the composition of the filters in terms of type of burnout materials, proportion of burnout materials and particle size. Filters made with sawdust exhibited higher bulk density (2.657g/cm^3) than those made with maize cob (2.608g/cm^3). Though sawdust and corn cob have similar characteristics, studies have indicated that sawdust has a slightly higher density than maize cob [19], hence the observed difference if filter properties. In terms of apparent porosity, filters made with sawdust had lower porosity (98.7%) than those made from maize cob (99.4%). The results of bulk density and porosity of filters made from different burnout materials suggest that sawdust left more residues in the pores than maize cob. The presence of residues in the pores might also improve the performance of the filters through adsorption and ion exchange.

Furthermore, filters made from maize cob had higher water absorption (41.31%) than those made with sawdust (38.4%). The above results indicates that filters made from sawdust might possess better mechanical properties than those made from maize cob. For instance, the higher water absorption of filters made from maize cob is likely to make them weaker and liable to damage, bearing in mind that water absorption by aggregate filters is an undesirable phenomenon. Though different burnout materials had different effects on the physical properties of the filters, analysis of variance indicates that the physical properties of the filters are not significantly affected by the type of burnout material ($P > 0.05$). In essence, maize cob which is an abundantly available agricultural waste can be used in place of sawdust in the production of ceramic water filters without compromising the integrity of the filters significantly. Other studies have also reported that maize cob can conveniently replace sawdust in other engineering applications [19, 20, 21]

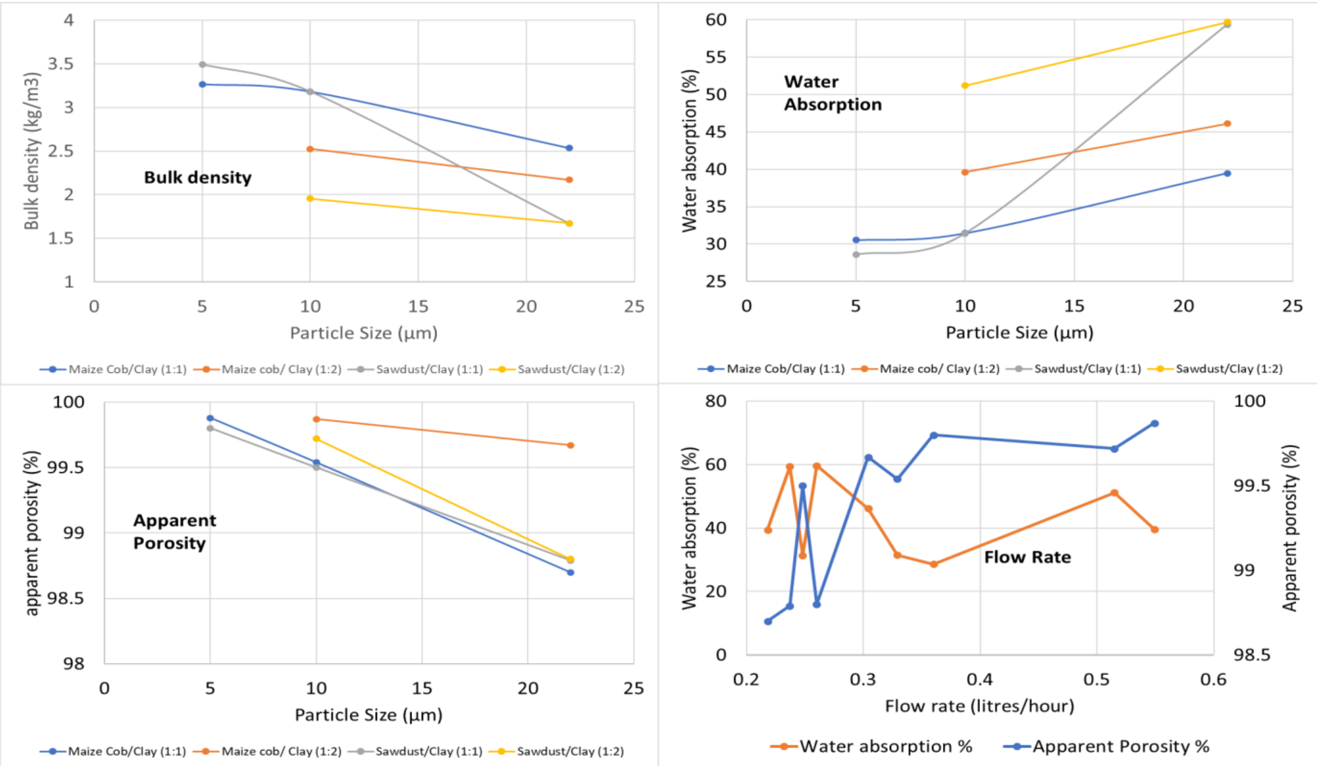


Figure 3: Plots of various filter properties versus particle size

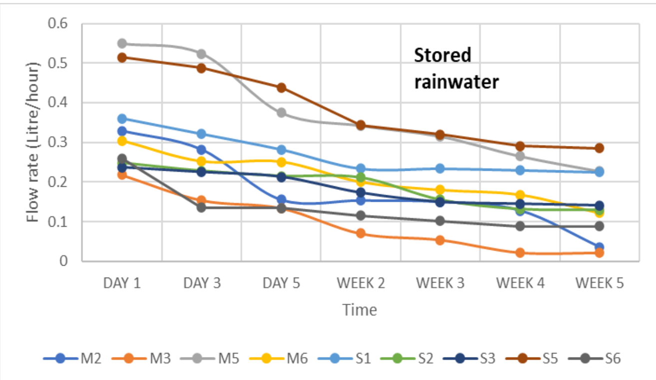
Though type of burnout material did not significantly affect filter physical properties, other variables were found to cause significant variations in physical properties. Particle size had significant effects on filter bulk density and water absorption but not on apparent porosity at 95% confidence level. The bulk density of filters made from 5, 10 and 22 µm particle sizes of burnout materials had bulk densities of 3.37, 2.75 and 2.32g/cm^3 representing a clearly an inverse (decreasing) relationship with particle size. Conversely, particle size had a significant but inverse effect on water absorption with values of 29.74, 37.06 and 45.54% for filters made from 5, 10 and 22µm particle sizes of burnout materials. Hence, smaller particle sizes of burnout materials tend to yield filters with better physical properties. Even though there was no clear trend for apparent porosity, results show that filters made with the smallest particles (5µm) had the highest average apparent porosity, while filters made from 10µm had the lowest apparent porosity. The effect of particle size on apparent porosity was not significant. The effect of burnout materials partly mimicked the effect of particle size on filter physical properties. Filters made from lower ratio (1:1) of burnout materials to clay yielded filters with higher bulk density (2.98g/cm^3) and lower water absorption (35.46%) than those made with 2:1 ratio (2.21g/cm^3 and 45.72% respectively). These represent significant effect of burnout material proportion on bulk density ($p = 0.002$) and water absorption ($p = 0.017$) at 95% confidence level.

Filters made from 1:1 ratio of burnout materials to clay had lower apparent porosity (98.82%) than those made from 2:1 ratio (99.47%). However, this effect is insignificant ($p = 0.241$) at 95% confidence level. Major factor that affects the filter performance is the ratio of combustible materials to the clay. Increasing the volume ratio of the combustible materials results in creating more pores in the filter which will likely make the flow of water faster and also compromise the filter's ability to reduce turbidity and microorganisms. As a result of this we ended up producing very fragile and less solid filter as in filters M4 and S4 which did not survive the firing process due to its fragility and high volume of combustible materials. It's necessary that the durability of the filter is not compromised since filter breakage is among the various factors for filter disuse [22].

3.2 Hydraulic Characteristics of the Ceramic Filters

The filtration rate ranged from 0.051 to 0.916L/hr with a mean of 0.354L/hr (Figure 4). These values are much less than flow rates reported elsewhere [7, 18], but within the range reported by other studies [12, 23, 24]. However, caution should be exercised in interpreting filter flow rates because the size of the filter is also a major determinant of flow rates. Based on type of burnout material, filters made with sawdust had higher flow rates (0.433L/hr) than those made from maize cob (0.291L/hr). It was earlier reported that filters made from maize cob had higher porosity that those made from sawdust. However, the relatively higher porosity of maize cob filters did not confer any hydraulic advantage on them. Analysis of variance further suggests that the difference in flow rates between filters made from maize cob and those made from sawdust was not significant ($p = 0.195$). It was also found that particle size of burnout materials did not have a significant effect on filter flow rate and the flow rates did not follow any trend of particle size order. While the lowest average flow rate (0.28L/hr) was obtained for the largest particle size of 22 µm, the highest average flow rate (0.43L/hr) was obtained for the intermediate particle size of 10 µm (Table 2). Only proportion of burnout material with respect to clay had a significant effect on filter flow rates ($p = 0.010$). Interestingly, doubling the proportion of burnout material also doubled the flow rate of the filters.

The average flow rate for burnout material to clay ratio of 1:1 was 0.24L/hr, whereas that for ratio 2:1 was 4.98L/hr. Hence, whereas the difference in burnout materials characteristics was not sufficient to significantly affect filter flow rates, increasing the quantity of burnout materials irrespective of the type, significantly increases the flow rate by creating more interconnected pores that facilitate the flow of water. However, it must be noted that increased flow rate is only desirable to the extent that it does not affect the treatment efficiency of the filters and it will always come at the cost of the structural integrity of the filters. In this study two pots with 2:1 ratio of burnout materials to clay did not survive the firing process. As expected, the flow rates decreased with time for all the filters tested. This might be due to clogging of the filter pores by suspended particles in the water samples used. It was also observed that water head increased the flow rate of the filters.



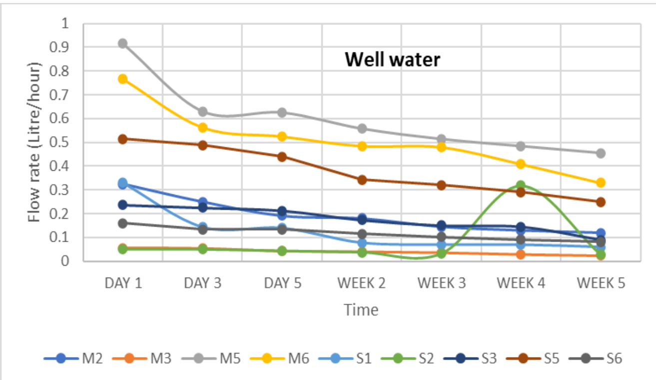


Figure 4: Filter flow rates

Table 2: Multiple comparison of ceramic filters of different properties

Category	Parameter	Bulk density	Apparent Porosity %	Water absorption %	Flow Rate (L/hr)	Coliform Removal (%)
Descriptives	Mean	2.63	99.10	40.02	0.354	99.7
	Minimum	1.67	94.94	28.6	0.051	99.0
	Maximum	3.493	99.87	59.71	0.916	100
	Standard deviation	0.57	1.13	9.49	0.226	0.240
Type of burnout Material	Mean for Sawdust	2.657 a	98.721 a	38.403 a	0.433 a	99.800 b
	Mean for Maize	2.608 a	99.419 a	41.306 a	0.291 a	99.575 a
	Pr > F(Model)	0.865	0.202	0.535	0.195	0.044

	Significance	No	No	No	No	Yes
Particle size	Mean for 5 µm	3.366 b	99.815 a	29.735 a	0.345 a	99.600 a
	Mean for 10 µm	2.753 ab	99.445 a	37.059 a	0.431 a	99.650 a
	Mean for 22 µm	2.322 a	98.596 a	45.543 a	0.280 a	99.775 a
	Pr > F(Model)	0.037	0.217	0.043	0.431	0.506
	Significant	Yes	No	Yes	No	No
Proportion of burnout material	Mean for 1:1	2.967 b	98.823 a	35.455 a	0.239 a	99.760 a
	Mean for 2:1	2.208 a	99.466 a	45.716 b	0.498 b	99.625 a
	Pr > F(Model)	0.002	0.241	0.017	0.010	0.247
	Significant?	Yes	No	Yes	Yes	No

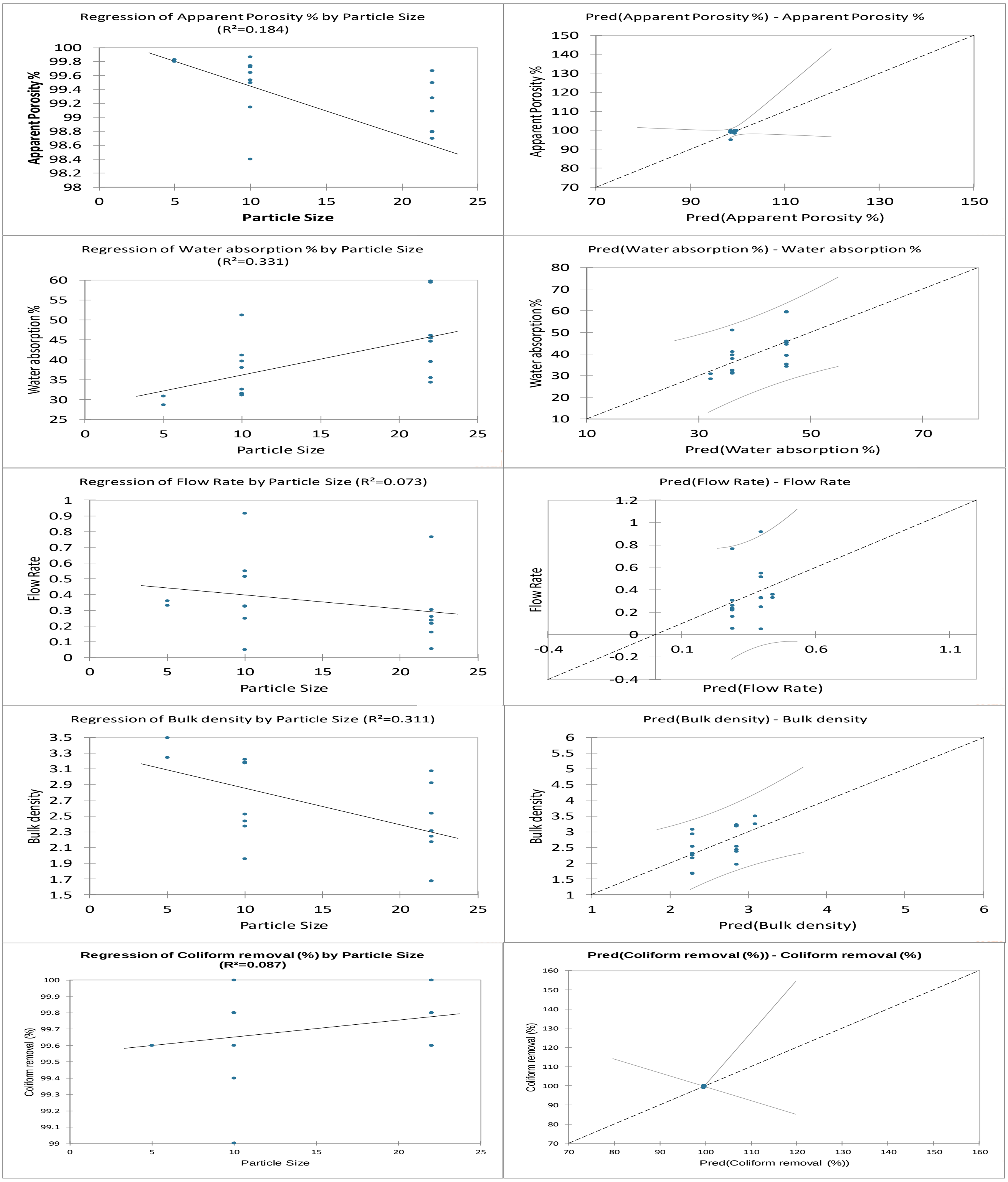


Figure 5: Regression of particle size against individual filter properties

Table 3: Correlation matrix of filter parameters

	Particle Size	Bulk density	Apparent Porosity %	Water absorption %	Flow Rate	Coliform removal (%)
Particle Size	**1**					
Bulk density	-0.557	**1**				
Apparent Porosity %	-0.429	-0.080	**1**			
Water absorption %	0.576	-0.965	-0.002	**1**		
Flow Rate	-0.270	-0.278	0.378	0.096	**1**	
Coliform removal (%)	0.294	-0.089	0.009	0.226	-0.596	**1**

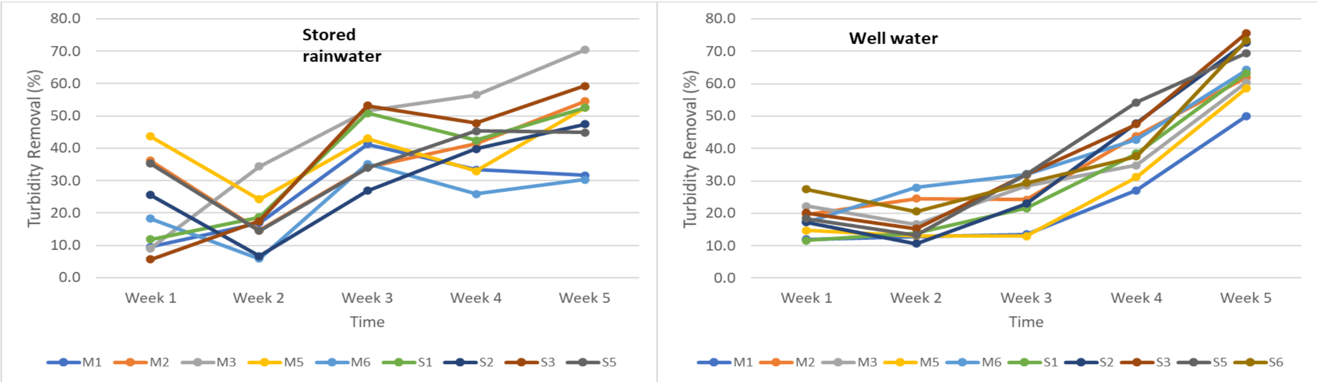


Figure 6: Filter performance with respect to turbidity

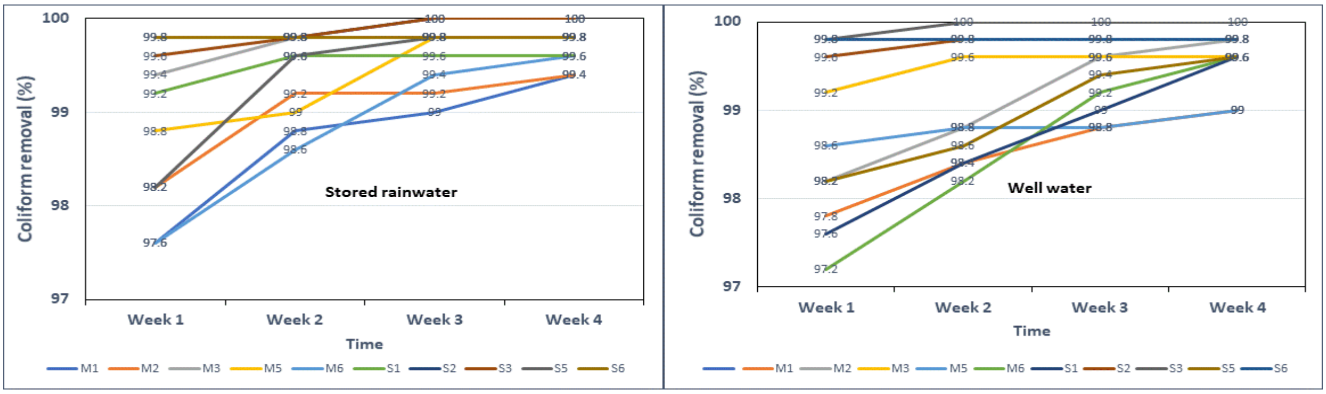


Figure 7: Performance of filters with respect to coliform removal

3.3 Performance of the Ceramic Filters

The turbidity of the raw water was quite low and ranged from 0.670NTU to 0.972NTU. The percent turbidity removal ranged from 9.1% - 43.7% on the first week to 30.6 – 70.4% on the fifth week of the test for filters made from maize cob; whereas the percent turbidity removal ranged from 5.7 – 35.3% on the first week to 44.9 – 75.6% on the fifth day for sawdust (Figure 6). These results show that filters made form maize cob had better performance with respect to turbidity removal at the initial stages of the process while filters made from sawdust performed better in the long term. This suggests that filters made from maize cob clog faster than those made from sawdust. Generally, turbidity removal efficiency increased from the first week to the last week of the investigation which is an indication of clogging of the filter pores and consequent reduction in flow rate over time. Increasing the combustible materials does not have any significant effect on the efficiency of turbidity removal especially when compared with other filters produced with a lower proportion of combustible material. The efficiency of turbidity removal is independent of the type of combustible material used. The generally low performance of the filters with respect to turbidity removal can be attributed to the low turbidity of the raw water samples used. In another study, Suribabu et al reported up to 100% turbidity removal [25].

The pH of the raw samples for the various weeks ranged from 6.2- 7.2 while that of the filtrate ranged from 6.8 - 7.1. The result of the pH obtained after filtration of each of the pots were close to the WHO standard for drinking water (6.50 to 8.50). Therefore, all ceramic pots filter designs met the WHO's maximum desirable concentration levels for drinking water. This was regardless of the source of water and also the sizes and proportion of the combustible materials contained in the filter.

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The major objective of point-of-use treatment units is to remove pathogens that might be present in water from source of that might have been introduced at the point of use. The efficacy of ceramic filters in the reduction of pathogens has been confirmed by several [26]. However, most of the studies investigated filters made from sawdust as burnout materials. Maize cob is still a new comer to the arena. However, being an abundantly available waste material, it will be interesting to explore its potential as a filter material. Coliform removal efficiency ranged from 99 to 100% with an average of 99.7±0.24. Filters made from sawdust had a higher average coliform removal of 99.8% than those made from maize cob with an average of 99.56% (Figure 7).

Though the disparity in their performance in terms of Coliform removal appeared narrow, analysis of variance confirmed that filters made from sawdust performed significantly better than those made from maize cob ($p = 0.044$) at 95% confidence level. In terms of particle size, there was an increase in efficiency of Coliform removal efficiency from 99.6 to 99.8% as the particle size of burnout materials increased from 5µm to 22µm. However, given the wide disparity in these particle sizes used, the slight increase in Coliform removal efficiency was not significant at 95% confidence level ($p = 0.506$). Furthermore, filters made with lower proportion (1:1) of burnout materials exhibited higher Coliform removal (99.76%) than those made with higher (2:1) proportion (99.63%). However, the proportion of burnout materials within the range used in this study did not significantly affect percentage Coliform removal ($p = 0.247$). In another study, it was reported that varying the percentages of burnout materials significantly affected the efficiency of E Coli removal by ceramic filters [27]

The performance of the filters was strictly time-dependent and generally improved over time. Some of the filters achieved 90% log reduction of Coliforms at the beginning of the investigation, while some achieved 99%. For filters made from maize cob, filter M3 made from 1:1 ratio of 22 µm maize cob to clay achieved 99% log reduction at the onset while the rest recorded only 90% log reduction for both well and rainwater samples. However, all filters made from sawdust achieved 99% log reduction at the start of the investigation, except for filter S5 for well and rainwater samples and filter S1 for well water sample only which recorded 90% log reduction. The Coliform percent log reduction increased steadily and by the third week, all the filters achieved 99% log reduction irrespective of type or proportion of burnout material and particle size. This confirms that in the absence of sawdust or short supply of it, maize cob can be effectively used to produce good point-of-use filters for domestic application in water-stressed communities. However, another important issue besides finding an alternative burnout material for ceramic filter production is the need to facilitate simultaneous pathogen removal and increased flow rate [7]. A negative correlation (-596) was observed between flow rate and Coliform removal (Table 3). This clearly suggests that any attempt made to improve the flow rate of the filters would invariably compromise the pathogen removal efficiency since the principal mechanism of pathogen inactivation by the filters if mechanical straining based on average pore size of the filters.

4.0 CONCLUSION

In this work, the feasibility of using maize cob as an alternative or complementary burnout material for the production of ceramic water filters was investigated and compared with filters made from. Though filters made from sawdust generally performed better than those made from maize cob, there was no statistically significant difference in terms of bulk density, apparent porosity and flow rate of the filters. However, filters made from sawdust exhibited significantly higher Coliform removal than those made from maize cob. Hence, sawdust is a better burnout ceramic filter material. However, in areas where sawdust is not available, maize cob can serve as an alternative burnout material.

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