Design and Evaluation of a Raw Water Treatment Chamber using Locally Available Materials

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Abstract* - Viable technology has to be developed to meet the increasing demand for quality water particularly in thickly populated, industrialized and economically viable society. In this research work, Periwinkle shells, Palm kernel shells, and Coconut shells were used to design a filter bed with Periwinkle shell of 0.20m size of a nut shell and 65m depth, a Palm kernel shell of 0.25m size of nut shell and 65m depth and a Coconut shell of 0.35m size of the nut shell and 30m depth was used for raw water treatment for rural communities. The coconut shells and palm kernel shell were separated from their materials, dried out under sun for 12 hours, while the periwinkle shell was sorted out to remove those that have spoilt. The obtained dry shells were crushed to desired size, washed, drain excess water, dry in an oven and sieve manually in a mechanical sieve shaker. Acidity test, sieve analysis, flow rate test and water analysis were carried out to determine the suitability of this local material to treat water for drinking. The result of the acidity test showed that the palm kernel shells and coconut shells met the specification and suitable to be used for filter bed material but that of periwinkle failed to meet the recommended specification i.e its weight is less than10% of the original weight. The results showed the filter water sample meet the WHO's standards requirement and zero CFU/100ml for the total coliforms and E.coli. Flow rate of the effluent water from the design nut shell filtration chamber yield an average of 30l/hr, which means that the nut shell filter could provide an adequate supply of drinking water for a typical household in the rural area. Based on the result of the study, the effective removal of total coliforms, reduction of turbidity and high flow, the nut shells filtration chamber could be recommended as a technology to be adopted on large scale treatment of water in rural area.

Keywords: Filtration, Underdrain, Coliform, Acidity, Flow rate

I. INTRODUCTION

The quality of drinking water is a powerful environmental determinant of health. Assurance of drinking water safety is a foundation for the prevention and control of various types of water borne diseases. Water resources have been the most exploited natural system since man strode on earth. On the other hand population growth, increasing living standard, wide spheres of human activities and industrialization have resulted in greater demand of good quality water particularly in thickly populated, industrialized and economically viable society. Viable technology has to be developed to meet the increasing demand for quality water.

The quality of water depends upon its origin and history. Many factors however, produce variations in the quality of water obtained from the same type of source. Climate, geographical and geological conditions all play important role in determining water quality [1]. Many rural areas today have been abandoned due to difficulties in treatment of raw water, higher standards of quality water and increasing population, with greater hazards from lapse in purification as well as higher costs of treatment.

Water treatment is aim at removing undesirable chemical materials and biological contaminants from contaminated water. Water treatments can also be designed for variety of other purposes, including meeting the requirements of medical, pharmacology, chemical and industrial application. Water is also treated to remove pathogens that can be harmful to human health. Quality water is essential for all social-economic development and for maintaining healthy ecosystems in rural areas.

In most rural areas visited the water available is not suitable for human consumption especially surface water due to the activities of man by allowing waste from dumpsites, fertilizers in agricultural fields as well as waste from soak away and pit latrines to migrates through the soils to the surface and groundwater [2]. It is therefore necessary to improve the quality of water and render it attractive and safe enough for human consumption

Simple techniques has been developed which can be used to treat water in rural areas such as alum, sieving, storage, solar disinfection and using filter bed designs with locally available materials [3]. Filtration process of raw water treatment has long been considered as a good method and technology for raw water treatment. In rural areas, studies show that continually operated filters are able to remove pathogenic organisms from untreated water with a high efficiency rate. In general, filters can reduce the total bacteria count (faecal and non-faecal organisms) by a factor of 103 to 104, and faecal bacteria (mainly E. coli) by a factor of 102 to 103 [4].

Slow sand filtration medium of operation was the adopted medium because slow sand filtration medium of operation was found by it cleaning technology that it purifies water without creating any additional sources of environment contamination and by its advanced high rate of filtration, its simplicity, and its low cost advantage, easy to operate, minimal maintenance requirement, and success in removing pathogenic micro-organism which makes it attractive option for rural communities and developing nations[5].

This study is to design a filter bed for raw water treatment in rural communities using locally available materials. It ensures that the construction, operation and maintenance of a filter bed are taking into consideration during the evaluation of locally available materials as an alternative for raw water treatment in rural area. The study also recommends simple technology for raw water treatment in rural area and specifies the right material for the design of a filter bed, for its optimal utilization.

II. MATERIALS AND METHODS

A. *Materials*

In this research work, periwinkle shells, palm kernel shells, and Coconut shells are the main local materials for the media that was considered. These materials were obtained from a local market called Oyigbo market in Lagos State, South Western part of Nigeria. The Coconut shells and Palm kernel shells were separated from their materials, dried out under sun for 12 hours, while the Periwinkle shell was sorted out to remove those that have spoilt. The finest and thickest grains of the nut shells were removed to maintain good porosity in the bed without affecting the successful elimination of bacteria and viruses. The nut shells were free of any clay or organic content. The raw water used was taken from a stream at Iree, one of the rural areas in Osun State and stored inside a covered bucket.

B. *Methods*

1) *Preparation of Nut Shells*

The obtained dry shells were crushed into desired sizes by a pestle and mortar and with a sledge hammer. The obtained nut shells were further crushed with a machine in order to get a uniform size. The crushed nut shells were finally passed through sifter of 4.00mm, 2.00mm, 0.0638mm to 0.038mm holes to eliminate pieces of wood, stones and other inorganic materials.

The sifter crushed nut shells were washed with a boiled water to remove the clay and organic matter that adhered to the grains of the nut shells and latter dried in an oven. The finished products are shown in fig. 1. in this specify order of Periwinkle shells, Palm kernel shell and Coconut shells

Fig. 1. Crushed nut shells (Periwinkle shells, Palm kernel shells and Coconut shells) respectively.

2) *Tests Applied on Sample*

Sieve analysis, specific gravity and acidic test were carried out on the filter materials to determine the performance of the layer of the filter media.

A) *Sieve Analysis*

Sieve analysis was performed by shaking 500g of weighed dried crushed nut shells for each of the shell and passed them through a series of batch of standard sieves of known finer aperture sizes (B.S sieves) for about 10minutes with a mechanical sieve shaker [6][7]. The mass of the shells retained on each sieve was measured and this enables the cumulative percentage by mass of the nut shells to be plotted against the relevant aperture sizes. The sieves used were specifically selected for analyzing the nut shells for the nut shells filter. The nut shell size distribution curve generated was used to determine the effective size d_{10} and d_{60} and subsequently $C_u(d_{60}/d_{10})$ was calculated which is the coefficient of uniformity. The values of d_{10} and C_u were then compared with Center for Affordable Water and Sanitation Technology (CAWST)'s recommended ranges for filtration [8].

b) *Specific Gravity*

The specific gravity (Gs) was measured in laboratory using a standard density bottle. The known weight of the oven dried nut shells (periwinkle shells, palm kernel shells and coconut shells) was put into different volumetric flask and was topped up with distilled water. According to [9], Gs for finer filter media should be between the ranges of 1.8 to 2.0 for the second layer between ranges of 1.6 to 1.8 for the coarse filter media between 0.9 to 1.96.

C) *Acidic test*

Most raw water is acidic in nature and contain substantial amount of salt which makes it of almost importance to determine the efficiency of a filter media in term of strength and durability [10]. 50g of weighed crushed nut shells were impregnated into sulphuric acid and hydrochloric acid for 24 hours and were brought out after the time from the acid and reweighed. The two weights i.e. before soaked into acid and after and results were recorded. The loss in the weight of the soaked crushed nut shells must not be less than 10% of the nut shells before soaked in acid were compared together.

3) Filter Bed Design

A multimedia filter bed was adopted consisting of three layers of periwinkle shells as filter media of fine nut shells followed by a transition layer of palm kernel shells as coarse nut shells and an under drain layer of coconut shells at the bottom. The depth and grading of the nut shells were determined. Three different effective sizes of each nut shells filter media were arranged in a filter chamber and were labelled as filter A, B, and C to determine the effectiveness of each and their flow rate.

The improvised filter chamber consists of two plastic buckets inserted into each other as shown in fig.2. The bottom of the upper bucket is perforated to allow water to pass through when the nut shells are arranged in layers and the bucket below has a tap to collect the filtered water.

Fig. 2. An improvised filter media chamber

Table 1. below shows analysis on the ranges of effective size of each nut shells that was used for each layer of the nut shells filter and it also specifies the height (depth) of the nut shells layers.

TABLE 1. DESIGN SPECIFICATION FOR DIFFERENT FILTER

Layer	***Types of nut shells***	***Effective sizes (mm)***			***Height depth (mm)***
		Filter A	***Filter B***	***Filter C***	
Upper	Fine periwinkle shells	0.15	0.18	0.20	65
Second (middle)	Coarse palm kernel shells	0.20	0.25	0.25	65
Lower	Gravel coconut shells	0.69	0.40	0.35	30

a) Flow rate test

The flow rate test was performed to ascertain the delivery rate of portable water to a rural household. The raw water was carefully poured on top of the filter chamber in a circular motion to promote even distribution through the depth of the filter bed and to avoid damage to the upper layer or the biological layer of the filter media. The filtration process continues until the raw water completely passed through the filter chamber. The filtered water was collected as shown in figure 2. and the result obtained from each filter was compared to optimum flow rate for a filter.

4) Water analysis

The filtered water samples were collected using two sterile 250ml plastic bottles. For each filter design the plastic bottles were filled with water up to 200ml leaving some spaces to allow shaking before analysis. The collected samples were delivered to Osun State Water Corporation, Ede laboratory for analysis within 2hrs of collection.

a) Physiochemical analysis

The water samples were analysed for temperature, colour, odour and taste, turbidity, P^H, conductivity, total dissolve solid, total alkalinity, manganese, iron, nitrate, copper and fluoride.

b) Bacteriological analysis

The Bacteriological characteristic of the filtered water was determined using multiple tube fermentation method (most probable number) for enumeration of both total coliform count and differential *Escherichia coli* count. Lauryl Tryptose Broth (LTB) along with fermentation tubes (Durham tubes) was used. A serial dilution of the water sample to be tested was made and inoculated into LTB growth media. Sample was then incubated at 35^oC for 48hrs for the presumptive test for total coliform count. After, the positive tubes were transferred to Brillant green lactose bile broth (confirmation test) and incubated for 48hrs at 35^0C, the growth or gas production confirmed the presence of coliform[12]

III. RESULTS AND DISCUSSION

A. *Results of tests on filter material*

Table 2.shows the results of the sieve analysis on the materials which were considered for this research work.

The nut shell distribution analysis curve generated from the results of sieve analysis is as shown in figure 3.

TABLE 2. RESULT OF SIEVE ANALYSIS OF FILTER MATERIALS.

Shell / Sieze size		Periwinkle			Palm Kernel			Coconut		
Sieve No	**Diameter (mm)**	**Mass retained(g)**	**% retained**	**% passing**	***Mass retained (g)***	***% retained***	***% passing***	***Mass retained (g)***	***% retained***	***% passing***
30	0.475	2.0	0.4	99.6	137.50	27.50	72.25	144.50	24.08	75.92
44	0/353	6.50	1.3	98.3	56.50	11.30	61.2	280.	46.06	29.86
52	0.251	14.00	2.8	95.5	28.40	5.68	55.52	146.5	7.75	22.11
72	0.211	50.50	10.1	85.4	89.10	17.82	39.7	58.5	9.75	12.36
85	0.178	108.50	21.7	63.7	180.00	36.00	1.7	64.5	10.75	1.61
100	0.152	203.00	40.6	23.1						
120	0.124	9.00	1.8	21.3						
150	0.104	21.0	4.2	17.1						
170	0.089	13.5	2.6	14.5						
200	0.076	16.5	3.3	11.2						
Pan		29.0								
Total		472.5			491.5			594		
		Mass of dry periwinkle shells + dish = 500g Mass washed sample = 500 - 472.5 = 27.5g			Mass of dry palm kernel + dish = 500g Mass washed sample = 500 - 491.5 = 8.5g			Mass of dry coconut shell + dish = 600g Mass washed sample = 500-491.5 = 8.5g		

The grain size distribution shows that the d_{10} of periwinkle was 0.106mm and the C_u was 1.6. The periwinkle has a nut shells filter material as the first layer (fine grains) falls within the specified range of 0.10 - 2.00 which makes it suitable for its purpose. Palm kernels has d_{10} of 0.18mm which falls within the specify range of 0.18mm – 0.30mm and C_u of 1.97 which is within the specified range of 1.75≤ 3. These values make the Palm kernel shell suitable as a good filter material for the design of the filter bed. The Coconut shell has d_{10} of 0.240mm and C_u of 1.8. This shell was able to meet the require range of 0.20 – 0.40 which makes it a satisfactory material for the filter media. The specify gravity of the three filter nut shell was calculated with Periwinkle shell having 1.9, Palm kernel shell with 1.8 and Coconut shell with 0.96.

Two different types of acids were used on the filter bed media and table 3. shows their reactions on the action with HCl and H_2SO_4 and change in colour. The results show that the palm kernel shells and coconut shells met the specification and suitable to be used for filter bed media but that of periwinkle fails to meet the recommended specification i.e its weight is less than10% of the original weight. If the periwinkle will want to be put into used as a filter material it is suggested that it should be 45% greater than that of the other two materials so that it will last longer. All the three materials (periwinkle shells, palm kernel shells and coconut shells) disintegrated on the action of H_2SO_4. Any water containing strong acid will affect the effectiveness of the filter media. Therefore the recommended pH of water to be treated with this designed filter media is 8.5

TABLE 3. HYDROCHLORIC ACID (HCL) TEST

Samples	***Weight of samples before in acid(g)***	***Weight when remove from acid(g)***	***Initial Colour***	***Final Colour***
Periwinkle shells	50	30	Brownish white	Brownish black
Palm kernel shells	50	46	Brownish black	Black
Coconut shells	50	49.5	Brown	Black

B. Result of Filter Bed Design

The flow rates of the filters ranged from about 5 l/hr to 10 l/hr and averaged of 7.5 l/hr. The flow rate result suggested that the nut shells filtration chamber is capable of providing sufficient amount of drinking water to three to three four of a household if the filter run for only two to three hours a day (recommended amount of drinking water is 7l per capita per day).

C. Result of Water Analysis

Table 4. summarizes the type and results of the test performed on water samples from each of the filter design.

TABLE 4. RESULTS OF PHYSIOCHEMICAL ANALYSIS

S/N	***Parameter***	***Raw***	***Filter A***	***Filter B***	***Filter C***	***WHO***
1	Appearance	Not clear	Not clear	Clear	Clear	clear
2	Colour (TCU)	60	25.00	30.00	20.00	15TCU
3	Taste and odor	Unobjectionable	Unobjectionable		Unobjectionable	-
4	pH at laboratory	7.40	6.60	6.60	6.60	6.5-8.5
5	Temp, (O^c) at laboratory	32.20	31.80	31.70	31.70	40
6	Free carbon-dioxideCO_2	-	-	-	-	-
7	Dissolved Oxygen (mg/l)	4.0	4.0	3.9	0.3	-
8	Total alkalinity (mg/l)	120.00	66.00	54.00	48	80
9	Total hardness (mg/l)	188.00	188.00	76.00	144.00	500
10	Calcium hardness (mg/l)	116.00	116.00	73.20	84.00	150
11	Calcium ions (mg/l)	46.40	46.40	28.80	33.60	-
12	Magnesium Hardness (mg/l)	72.00	72.00	4.000	60.00	30-150
13	Magnesium ion (mg/l)	18.00	18.00	1.00	15.00	30-150
14	Chloride ion (mg/l)	30.00	16.00	18.50	15.00	75
15	Iron (mg/l)	0.100	0.080	0.064	0.060	0.3
16	Silica (mg/l)	11.30	2.700	2.160	3.600	-
17	Nitrate Ions	4.00	1.50	2.100	2.100	50
18	Nitrite nitrogen	0.903	0.337	0.474	0.474	0.2
19	Conductivity	297	365	399	298	1000
20	Flocculation (ppm)	60.00	25.00	30.00	15.00	-
21	Carbonate (mg/l)	120.00	66.00	54.00	102.00	-
22	Bicarbonate, HCO^-_3 (mg/l)	73.20	61.00	73.20	61.00	-

pH was measured using a pH-probe. There was little significant change in the pH before and after filtration as show in table 4. These indicate that the nut shells are inert. The average turbidity of the influent water is 1.0 NTU for the entire nut shell filter. They are below the maximum recommended turbidity limit of 100NTU. This suggests that it may be necessary to pre-treat the source water simply by letting the water settle before pouring it into the filtration chamber, otherwise, it becomes necessary to clean the filter more frequently since more clogging is expected to occur with higher levels of source water turbidity. Iron is one of the major metal present in the filter water samples and the concentration was recorded as shown in Table 4. Iron helps transport oxygen through human blood and it is not considered hazardous to human health. Conductivity is a measure of the ability of water to carry electric current. The result also showed that the level of conductivity of the water sample were within the range of WHO standardrecommendation.

The result of bacteriological examination shown in Figure 5. confirms that the nut shells filtration chamber designed is an effective technology at removing total coli forms. The longer the filter is put into use there by getting the filter bed to fully mature quickly i.e. increasing the ripening period of the filter bed, in which the filter can effective remove contamination.

TABLE 5. BACTERIOLOGICAL EXAMINATION

Sample No	***Description of samples***	***Ph***	***C/R***	***Colonies per CC Growing on Nutrient Agar At 37 ^{0}C in 48 Hours***	***Presumptive results of Coliform organisms At 48 Hours of incubation At 37^{0}C***	***Most probable number of bacteria per 100mlof Water Sample***
1.	Design filter A	6.6	Nil	-	0 5 1	07
2.	Design filter B	6.6	Nil	-	1 4 0	13
3.	Design filter C	6.6	Nil	-	0 0 0	0
4	Stream water (Raw)	7.4	Nil	-	1 4 5	160

IV. DRAWBACKS

The first drawback of the filter is that it takes time for the biological layer to fully mature. During this ripening period which is estimated to be 2 weeks, the filter is less effective in removing contamination.

The second drawback is that the efficiency of the filter is limited by the turbidity of the source water. In the monsoon season, the performance of the filter will be compromised. Pre treatment steps may be necessary to reduce the turbidity of the influent water to the filter

V. CONCLUSION

This experimentation gives a favourable result with filter C having a periwinkle shell of 0.20m size of a nut shell and 65m depth, a palm kernel shell of 0.25m size of nut shell and 65m depth, a coconut shell of 0.35m size of the nut shell and a 30m depth selection and as well as, on how fully well the filter mature, the total number of coliforms can be removed. Flow rate measurement of the effluent water from the design nut shell filtration chamber yield an average of 30l/hr, which means that the nut shell filter could provides an adequate supply of drinking water for a typical household in the rural area.

VI. RECOMMENDATIONS

Based on the results of the study, the effective removal of total coliforms, reduction of turbidity and high flow, the nut shells filtration chamber could be recommended as a technology to be adopted on large scale treatment of water in rural area. However there is needs to work hand in hand with a monitoring plan to ensure correct construction, operation and maintenance procedure to be followed is necessary. The monitoring plan is necessary to increase the effectiveness of the filters.

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