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DEVELOPMENT OF A SLOW SAND WATER FILTER WITH ACTIVATED CARBON USING LOCALLY SOURCED MATERIALS

by

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Abstract

Water treatment plays a greater role in the water supply chain. It helps in the sustainable management of vital water resources alongside water conservation and efficiency. Sand has been used to purify water for over a thousand years and it still remains the dependable methods of making water fit for drinking. A biological sand filter (BSF) was developed using locally sourced materials. The filter media comprising of gravel, fine cloth, sand and layer of activated carbon. The activated carbon layer was activated with a 25% CaCl m/m solution. This design was chosen over others for its low cost and simplicity. Parameters monitored included absorbance, COD, total coliforms, turbidity, conductivity, temperature, pH, total solids, and flow rate. The performance of the filter was evaluated by analyzing both the raw and treated water samples in the laboratory. The flow rate was also determined by allowing a known volume of untreated water to run while monitoring the time. The water quality analysis showed an appreciable reduction in calcium, magnesium, potassium, sodium and iron in untreated water to 14.62, 17.46, 1.43, 2.39, and 0.1 in treated water respectively. The pH and E.coli was 6.2 and 10 respectively. Taste, colour and turbidity were also tested for and the result shows an appreciable reduction. The flow rate was evaluated to be 0.01692m^3/hr (i.e. 16.92L/hr). The filter is cost effective and easy to construct, operate and maintain.

Keywords: Development, Water Filter, Activated Carbon

Background to the Study

Among the many essential elements for the existence of human beings, animal and plants, water is rated as one of the most important elements for human living. Man can survive for weeks without food but a few days without water (Adekunle & Adejuyigbe, 2012).

A satisfactory water supply for domestic purposes, such as human consumption and personal hygiene, is characterized by adequate standards regarding the availability of water, its quantity, its quality and the reliability of the supply (Van Dijk & Oomen, 2002). Data collected periodically by international agencies show that a substantial part of the world's population, in particular many people in developing countries, do not have reasonable access to adequate and safe water supply (Van Dijk & Oomen, 2002).

The presence of a safe and reliable source of water is thus an essential pre-requisite for the establishment of a stable community.

Standards of Water Quality

The World Health Organization established minimum criteria for drinking water.

Table 1. Drinking Water Standards

Water Quality Parameter	Measured as	Highest Desirable Level	Maximum Permissible Level
Total dissolved solids	mg/l	500	2000
Turbidity	FTU	5	25
Color	mg pt/l	5	50
Iron	mg Fe^{+}/l	0.1	1.0
Manganese	mg Mn^{++}/l	0.05	0.5
Nitrate	mg NO_3/l	50	100
Nitrate	mg N/l	1	2
Sulphate	mg $N04^{2}$-/l	200	400
Fluoride	mg F^{-}/l	1.0	2.0
Sodium	mg Na^{+}/I	120	400
Arsenic	mg AS^{+}/l	0.05	0.1
Chromium (hexavalent)	mg Cr^{6+}/l	0.05	0.1
Cyanide (free)	mg CN^{+}/l	0.l	0.2
Lead	mg Pb/l	0.05	0.10
Mercury	ng Hg/l	0.001	0.005
Cadmium	mg Cd/l	0.005	0.0100
Taste	--	--	--
Chloride	Cl/l	200	600
Zinc	Zn/l	5	15
Calcium	Cl/l	75	200
Magnesium	Mg/l	30	150
Sulphate	SO_3/l	200	400
Total hardness	CaCO/l	100	500
Nitrate	NO_3/l	45	-
PH Value	pH meter	7-8	6.5-9

Source: World Health Organization. (1998)

Water Treatment Processes or sections include Sedimentation, Coagulation, Filtration, Disinfection, Softening and Aeration among others. These processes have been satisfactorily established and adopted in all the developed countries of the world and most urban centers of developing countries. However, the adoption of this technology for the growing population of the developing world (rural areas to be specific) is becoming a challenging task (Ijaduola *et al.*, 2011). The main goal is the development of water treatment unit, which is cheap, simple, and easy to construct, maintain and operate. Basically the process of filtration consists of passing the water through a bed of sand, or other suitable medium at low speed. In order to achieve the final degree of clarity, the influent water from the settling basins must be of fairly low turbidity (Ijaduola *et al.*, 2011). This degree of settling may vary with the type of filter adopted.

Mahlangu *et* al. (2011) stated that an ideal water treatment system for developing countries should be able to remove all chemical and microbial contaminants in one single filtration process. Low-cost and readily available materials which are efficient in removing contaminants from drinking water are considered to be a solution for providing clean water in rural areas of developing countries.

Most rural dwellers in Nigeria have no access to treated water and cannot afford to purchase advanced water treatment equipment for the treatment of their water. The need for water treatment for the rural dwellers is highly crucial and need to be accentuated. The development of a biosand filter is a good solution for any household seeking for a cheap and effective raw water treatment measure. Therefore, the objective of this research is to design, construct and carry out a performance evaluation of a slow sand Water Filter with activated carbon using locally sourced materials.

Methodology

Material Selection

Component parts of the filter

Filter tank: The filter tank houses the filter media i.e. the gravel, coarse sand and fine sand and the fine cloth.

Clear water tank: **C**lear water tank collects the filtered water from the sand filter tank.

Filter media: These include the gravel which allows water to drain freely from the sand bed while preventing sand from escaping to the outlet tank. It comprises of gravel, fine (2-5mm) to coarse (7-15mm) in separate layers. fine cloth, coarse sand, fine sand. It is recommended sand grain be round to avoid packing and about 0.3mm in diameter to maximize surface area and a layer of activated carbon.

Activated Carbon: Activated carbon also called activated charcoal was made from coal processed to charcoal activated with calcium chloride with small volume pores that increase the surface area available for absorption or chemical reactions.

Stand: This is the frame on which the filter tank and the clear water tank are placed. It is made of wood.

Diffuser plate: The lid of a plastic 50litres bucket was used as diffuser plate. The lid was perforated round using a heated 2mm diameter nail. The holes were spaced 2cm from each other. The plate rests on the top edge of the filter tank above the resting water level. The main function of the diffuser plate is to distribute the fall of the water over the whole filtering surface to avoid damage to the upper sand layer and the destruction of the biological layer. The diffuser plate also serves to sieve the larger impurities carried by the water, such as leaves, branches and larger insects.

Design Consideration and calculations

i Size of filter

The biosand filter is made of a truncated trapezoidal shaped Perspex (transparent) bucket cut into nine sided (nonagon) of dimensions 45cm × 46cm × 37cm.The bottom screen is 29cm in diameter from the base which serves as reservoir for the filtrate.

ii Filter media

The filter media comprises of fine sand bed(6cm), coarse sand bed(7cm), gravel bed(12cm) and activated carbon bed(7cm)

Area of filter media $A_m = (\frac{b1+b2}{2})h$ 1

Where;h is the total height of the filter media

iii Flow rate

Flow rate (Q), was calculated using:

$$Q = \frac{v}{t} \qquad 2$$

where; Q = Volume flow rate in L/s, v = Volume of water collected in the clear water tank in liters, and t = elapsed time in seconds. When v = 1*ltr* and t = 236*s*

v Design Drain pipe

P.V.C. pressure pipe of diameter 2.54cm (1 inch) and length 53cm was used for the construction of the filter drain.

Area of drain pipe $A = \pi d \times l$ 3

where; π = ratio of the circumference to the diameter of a circle

d = diameter of the pipe

l = length of pipe

vii Wooden stand

A two steps wooden frame *(Apa* wood) was used to support the filter and clear water tank. The height of the first and second step is 38 and 25cm respectively and the breath is 36cm.

viii Flow velocity

The distance of water travel through filter media and drain pipe per unit time was calculated using: $V = Q/A$ 4

where: V = Velocity, in m/s, Q = Discharge in m^3/s and A = Cross-sectional area of flow in m^2/s

Flow velocity of tank, $V_t = Q/A,$ 4a

Flow velocity of pipe, $V_p = Q/A,$ 4b

ix Flow-through rate

The minimum time interval (T) for the particle to travel to the next point where filtrate could be collected after varying the discharge in hours was determined using the formula:

$$T = \frac{(L_t/V_t + L_p/V_p)}{3600} \qquad 5$$

where: L_t = length of tank segment from sand bed to drain pipe in m, L_p = length of pipe segment from within the tank to the point where filtrate could be collected in m,

V_t = velocity of water in the tank in m/s and V_p = velocity of water in the pipe in m/s.

Fig.1: Slow sand water filter

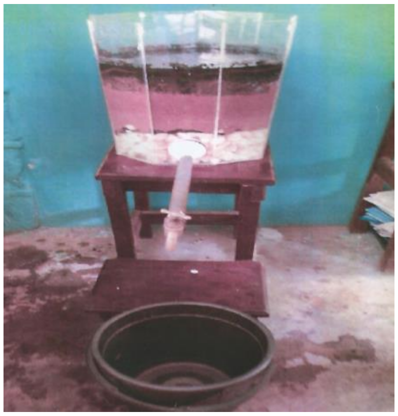

Fig. 2: Slow sand filter with activated carbon

Performance Evaluation

The flow rate was determined. Bacteriological, physical and chemical analysis was done both on the raw water(influent) and filtered water (effluent) from the slow sand filter. Water to be filtered was poured through the diffuser basin which spreads on the filter bed. Water seeped through the filter media to the base of the tank where the drain pipe was located and moves into collector (bucket). Flow rate was measured when the filter tank was filled to its maximum level, thus providing a constant head when the flow rate was measured. Known volume of water was collected from the drain pipe and the elapse time was recorded with the aid of a stopwatch. Adequate time was considered for the water particles to travel through the bed before the filtrate was collected at a point for analysis**.**

Water Analyses

Water samples were collected using two 750ml plastic bottles from both the influent (raw water) and effluent (filtrate) from the drain pipe. Both the influent and effluent were analyzed for physical, chemical and bacteriological characteristics which are taste, odour, colour, turbidity (appearance), Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), pH, electrical conductivity (EC-2), exchangeable cat ions (calcium, magnesium, potassium, and sodium), total hardness, iron, colonies growing on nutrient agent at 37^oC in 24 hours, most probable numbers of coliform organisms per 100cc, most probable numbers of E. coliform per 100cc, and most probable numbers of salmoneth per 100cc.

Figure 2. Raw water sample (influent)

Figure 3. Filtered water sample (Effluent)

Results and Discussion

Flow rate effluent is $0.02376m^3/hr$ through the outlet pipe. The flow velocity is 0.0000014m/s.

Flow through rate is 0.10915

Water Analysis

Table 2, shows the results of the water analysis carried out on the raw water and the filtered water respectively.

Table 1. Raw Water Analysis Result

Standard Diagnostic Characteristics	Raw Water	Treated Water
Taste	Mild	Tasteless
Odour	Odour	Odourless
Biological Oxygen Demand (BOD)	5.6	1.3
Chemical Oxygen Demand (COD) (Mg/l)	7.2	12.2
Colour (Hu)	10	6.8
PH-Water (suspension 1:2) (pH)	7.2	5.3
EC-2 (Extract $1{:}2^1/_2$) us/cm	83.7	26.8
Echangeable cations: Ca (Mg/l)	28.0	12.6
Mg (Mg/l)	20.0	16.0
K (Mg/l)	0.72	0.31
Na (Mg/l)	1.63	0.82
Turbidity (NTU)	6.7	0.91
Total Hardness	48.2	15.8
Iron (Mg/l)	0.65	0.12
Colonies/cc Growing on Nutrient Agent at 37^{o}C in 24hours	40	12
Most Probable No. of Coliform Organism Per 100cc	8.2	5.0
Most Probable No. of E-Coli Per 100cc	12.5	10
Most Probable No. of Salmoneth Per 100cc	Nil	nil

Discussion

Flow Rate

The biosand filter produced flow rates of between 15 and 18 Liters per hour. The flow rate of the biosand filter was higher in the first hour of filter run and decreased with time of filter run. This observation supported the findings made by Buzunis, (1995), that a decrease in the height of the water above the sand bed results in a decrease in the flow rate. However, with clogging due to filtration of highly turbid water, flow rates lower than the recommended limits was obtained.

Water Analysis

When the results of the water analysis for influent was compared with the standard by the World Health Organization (WHO), it was observed that the influent was not suitable for drinking. The results obtained from the laboratory for effluent shows an appreciable degree of treatment had tremendously taken place when the designed filter was used.

Physical Parameters

The attractiveness of water to human senses is determined by physical parameters. The common physical parameters are color, taste, turbidity, total solids, and temperature. The maximum permitted level by WHO and NSDWQ for color is 15 TCU. Though the raw water used for this project was found to be 10 TCU which falls within the standard set by WHO and NSDWQ, but the filter was efficient in reducing the color to 6.8 TCU.

The raw water used was found to be mild when tasted. The filtered water was tasteless when examined at the laboratory. Significant reduction in turbidity was observed. The biosand filter reduced turbidity from 6.7 NTU to <1 NTU and this finding supported the observations made by Buzunis, (1995) that biosand filters have higher turbidity reduction efficiencies compared to fast sand filters.

Chemical Parameters

The biosand filter achieved high and low removal of chemical characteristics regardless of whether the initial concentration in the untreated water was lower or higher than the standards set by the WHO and NSDWQ.

The values of calcium, magnesium, potassium, sodium and iron present in the raw water were analyzed to be 28.0mg/l, 20.0mg/l, 0.72mg/l, 1.63mg/l, and 0.65mg/l respectively. Though the values calcium, magnesium, potassium and sodium found in the untreated water falls within the stipulated standard set by the WHO and NSDWQ, there was reduction in the values to some safer quantities. Calcium was reduced to 12.6 from the initial 28.0mg/l, magnesium was reduced from 20.0mg/l to 16.0, potassium went down to 0.31mg/l from 0.72 and sodium from 1.63mg/l to 0.82mg/l.The value of iron in the raw water which was 0.65mg/l, was higher than the maximum permitted value set by the Nigeria Standard for Drinking Water Quality (NSDWQ) to be 0.3mg/l. The iron was reduced to 0.12mg/l after filtration which made it fit according to the NSDWQ standard.

Bacteriological Parameter

Results of bacteriological analysis of raw water shows that the *E.coli* count in influent exceeds the maximum permitted level for microbiological limits in the Nigeria Drinking water standard which is 10 (NSDWQ, 2007). Reduction in *E. coli* count was observed using the biosand filter. Within the filter bed, the presence of protozoa, bacteria, algae and other forms of life contributes to the removal of pollutants (Banda, 2011; Bonnefoy, 2002) including the *E. coli* (Mwabi *et al*., 2013).

Biological activity and protistan abundance at the top layer of the *schmutzdecke* could probably be the mechanism of *E. coli* removal in water. In the study of Unger and Collins (2006), *E. coli* removal in slow-rate biological filters occurred primarily at the interface and was related to *schmutzdecke* biological activity and protistan abundance. Elliott *et al*. (2011) also noted that the activity of the microbial community within the filter is responsible for the reduction of pathogens and that the most likely biological pathway is the production of microbial exoproducts such as proteolytic enzymes or grazing of bacteria and higher microorganisms on other organisms.

Conclusion

Biosand filters form part of the many emerging technologies being developed from locally available materials, for the removal of contaminants from water in rural areas to make the water suitable for use by low-income rural people of developing countries. The Biosand filter is cheap to construct and maintain. The filter was observed to have flow rate which if operated for 5 to 8 hours a day could be suitable for use by a family of 5 to 6 persons for the production of clean water for both drinking and cooking purposes. The size of the filter makes it convenient for the users to position it in an area where food is prepared and hence encourages the use and maintenance of the filter. The biosand filter had higher removal efficiency of chemical contaminants calcium, magnesium, iron, colour, turbidity and *E. coli* to levels allowable by WHO (1998) and NSDWQ (2007). and hence can be used for production of higher quality water at lower costs.

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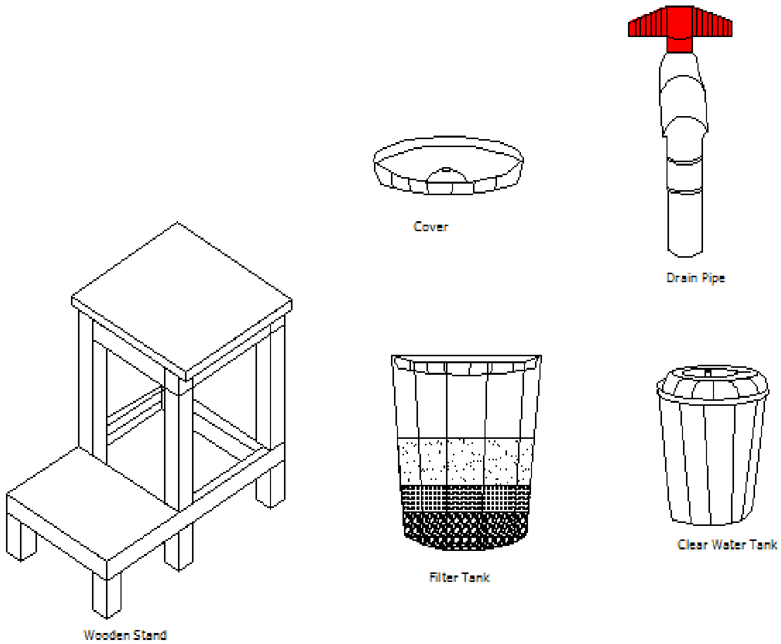
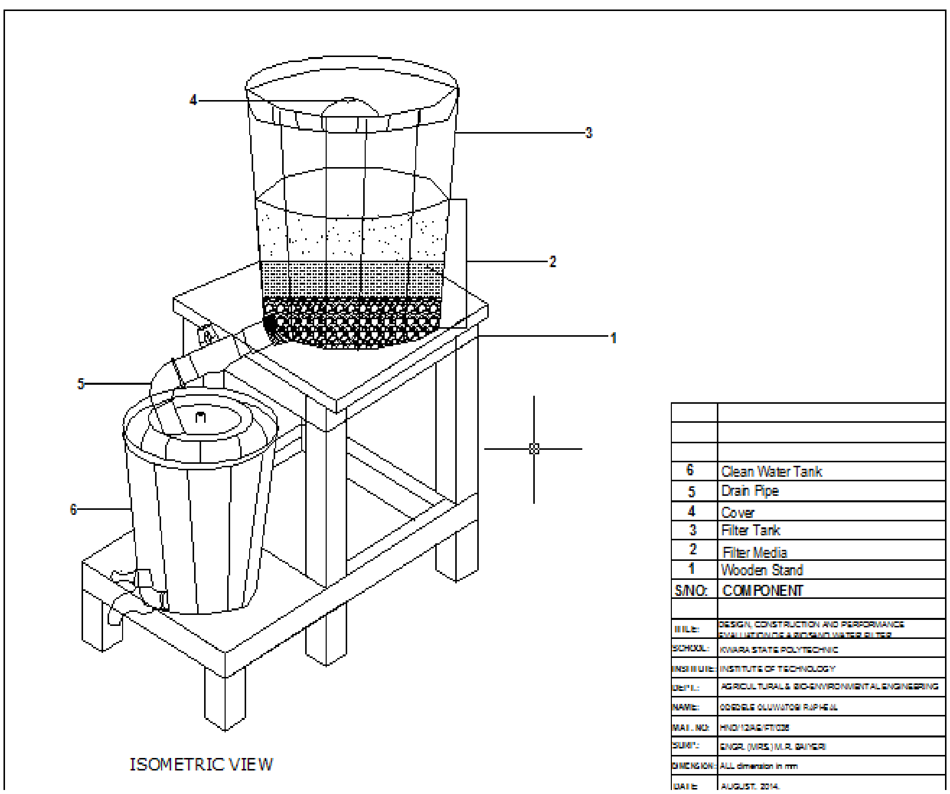
Appendix


Cover
Drain Pipe
Wooden Stand
Filter Tank
Clear Water Tank


4
3
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ISOMETRIC VIEW
6 Clean Water Tank
5 Drain Pipe
4 Cover
3 Filter Tank
2 Filter Media
1 Wooden Stand
S/NO: COMPONENT
DESIGN, CONSTRUCTION AND PERFORMANCE
SCHOOL: KWARA STATE POLYTECHNIC
INSTITUTE OF TECHNOLOGY
AGRICULTURAL & BIO-ENVIRONMENTAL ENGINEERING
ALL dimension in mm
AUGUST, 2014.