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Development of a Simplified Slow Sand Filter for Water Purification

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ABSTRACT: This study reports the development of a simplified slow sand filter with granular carbon for water purification which could be used for teaching. It was fabricated using transparent perspex glass for the filter chamber, PVC pipe, fine sand, coarse sand and granular carbon for removal of physicochemical and pathogens in the contaminated water. The filter has a 50 litres storage tank from which raw water flows into the filter chamber through the pipe. The filter chamber (30 by 30 cm and 100 cm high) has 10 cm layer of granular carbon, three sand layers as the filter bed (30cm depth with grain size 0.20 mm, 20 cm with grain size 0.35 mm and 10 cm with gravel 6.00 mm). Water samples were collected from Asa River. The water sample was poured into the water filter; water samples were collected and analyzed. The filter has a capacity for producing 15.25 litres/h of clean water. The values of turbidity, pH, Electrical conductivity, Calcium, Magnesium, Sodium, Potassium, Iron II, Colonies growing on nutrient agent at 37°C in 24 hours and E-Coli for the filtered water were 0.91mg/l, 6.7, 26.8µS/cm, 12.6mg/l, 16.0mg/l, 0.82mg/l, 0.31mg/l, 0.12mg/l, 12 and 8, respectively while the corresponding values for non-filtered water were 6.7mg/l, 7.2, 83.7µS/cm, 28.0mg/l, 20.0mg/l, 1.63mg/l, 0.72mg/l, 0.65mg/l, 40 and 13. The filter reduced E-Coli present in the water by 69%. The slow sand water filter could be used in the school laboratory as a water treatment prototype device for teaching students.

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Potable water is indispensable for survival of human race and the demand for potable water is increasing because of the population growth. Potable water is the water that is free from pathogens, colourless, odourless and the chemicals composition are within the acceptable limits which is safe for consumption without causing any disease to man. Raw water from streams, rivers, ponds, lake and even rain water from roof are usually contaminated with pathogens that can cause some deadly diseases to man. Contaminated water can cause water-borne diseases such as typhoid, cholera, dysentery and some other diseases (Hammer and Hammer, 2012). There is need for purification of water from ponds and streams to prevent certain diseases in the rural areas where tap water (public treated water) is rarely available. There is also need to expose undergraduate students to some basic methods of water purification in the treatment plant using a simple or prototype water filter in the school laboratory. Modern water filtration devices are available but some of them needed electricity to power its operation which is lacking in rural areas and even in some laboratories in the developing countries. A water filter such as slow sand water filter does not

requires electric power for its operation, relatively cheap and could be used in school laboratories for teaching students on how filtration is done in the water treatment plant and could also be used in rural areas for water purification. Slow sand water filter is effective for water purification and it uses the filtration method to remove dissolved particles and microorganisms in the water (Basak, 2003 and Chatterjee, 2007). A slow sand water filter could effectively remove some toxic chemicals and hazardous materials from the water (El-Harbawi *et al.*, 2010). Basak (2003) also indicated that slow sand filter could improve the chemical, physical and biological properties of water when water is allowed to flow through it. WHO (1996) stated that slow sand filter could remove between 98 and 99 % of the diseases causing pathogens and this could significantly reduce the diseases caused by pathogens.

Filtration by silk cloth to remove debris and other particles in rural areas in olden day was not effective for water purification because it does not remove colour, odour, taste, most chemicals and does not totally remove pathogens that could cause deadly

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disease to man. Slow sand filter differ because it uses biofilm layer that grows naturally on the surface of the wet sand called *schmutzdecke* to trap and kill the bacteria in the contaminated water. Biofilm is the biological active film that coats the sand media of a slow sand filter and it helps in the removal of contaminants (Hendrick, 1991). The sand acts as a substrate upon which the biological film developed (Wirojanagud *et al.*, 1998). The development of biofilm layer is possible due to the absence of pre-disinfectant on the sand filter bed (Lahlou, 2000). The biofilm layer (*schmutzdecke*) normally develop 2 – 3 weeks after the construction of the slow sand filter and the filter bed must be wet (Buzunis, 1995). The water reservoir that supplies water to the filter chamber could be 1 to 1.5 m above the sand bed. The space above the sand filter bed to the top of the filter chamber is called supernatant or top-water and it provides the pressure that carry the water through the filter bed. When water flows downward through the filter bed, it enters the intensely active biofilm layer, where various microorganisms entrapped, digested and break down the organic matter contained within it (Shoemaker, 2014). Visscher *et al.* (1987) recommended three layers for slow sand filter, the grain size for the layer and the depths (thickness) for grain. For the coarse sand of diameter 1.0 – 1.4 mm (10 cm thickness), gravel of diameter 4.0 – 5.6 mm (10 cm thickness) and gravel of diameter 16.0 – 23.0 mm (15cm thickness). Visscher *et al.* (1987) recommended a minimum depth of 60cm of filter bed for purification of water by slow sand filter. The slow sand filter chamber could be constructed from galvanized sheet or plastic material (PVC). The objective of this study was to develop a simple laboratory slow sand filter with granular carbon and to determine the effect of the filter on some physical, chemical and biological properties of a river water.

MATERIALS AND METHODS

Description of the water filter: The laboratory and household water filter was designed and fabricated (developed) using locally available materials that are relatively cheap and readily available in Ilorin, Kwara State, Nigeria. The water purifier (water filter) was fabricated using a transparent perspex glass of thickness 4 mm for the filter chamber. The filter chamber was 30 by 30 cm and 100 cm high. The filter chamber was transparent perspex glass to enable students see the movement of water through the filter bed before it is collected at the outlet whenever the filter is used for demonstration. The sand used as filter medium was freely running sand sieved through 0.20 mm, 0.35 mm and gravel sieved through 6.00 mm. The sand was put in water for 48 hours, thoroughly washed to remove organic matter, colloids and some

soluble minerals in water, and sun-dry for 3 days. Washing of sand filter material is necessary to have a clean filter bed that free from debris, organic matter, clay particles and some soluble chemicals.

World Health Organization (WHO) recommended that a non-reactive material such as plastic (PVC) and fiberglass should be used for the filter chamber. The filter chamber was fabricated using transparent perspex glass so that flow of water through the filter bed could be seen and easily monitored by the students when the filter is being used for demonstration. The filter chamber (30 by 30 cm and 100 cm high) has 10 cm depth containing granular carbon (sieved through 2 mm) put in a muslin bag and three sand layers as filter bed of 60 cm depth (30 cm grain size 0.20 mm, 20 cm grain size 0.35 mm and 10 cm gravel 6.00 mm). The water filter has a 50 litres storage tank for the raw water to be filtered and it is connected to the filter chamber by 25.4 mm (1 inch) diameter PVC pipe. The water outlet from the storage tank through the pipe has a control tap for regulating the flow of water from the tank into the filter chamber.

The supernatant is the water reservoir space above the sand filter layer. The depth between the biofilm layer and top of the filter chamber was 30cm. The depth of water in the supernatant provides the required pressure (pressure head) to push the water through the filter media. The supernatant must be filled with water to keep the biofilm layer moist for proper functioning of the slow sand filter. The exploded view and picture of the slow sand filter were shown in Figures 1 and 2.

Fabrication of the slow sand filter: A 30 by 100 cm (4 pieces) was marked out on the perspex glass and cut using hacksaw to fabricate the filter chamber. Four pieces of the perspex glass was put side by side and gum together along the edges using silicon gum to form the filter (30 by 30 cm and 100 cm high). The filter has a 50 litres storage tank and it is connected to the filter chamber by 25.4 mm diameter PVC pipe. The water outlet from the storage tank through the pipe has a control tap for regulating the flow of water from the tank into the filter chamber. The bottom of the filter chamber was covered with 30 by 30 cm perspex glass and it has a hole of 2.54 cm where drain pipe (2.54 cm diameter and 8 cm long with control tap) is fixed. The drain pipe could be opened when there is need to remove dirty particles from the bottom of the filter chamber.

The filter chamber was filled with 10 cm gravel (sieved through 6 mm), a silk membrane (30 by 30 cm) was put on the gravel layer, coarse sand of gain size 0.35 mm was put after the gravel to a thickness of 20 cm

and fine sand of grain size 0.20 mm was put on the coarse sand to a depth of 30 cm. Granular carbon (sieved through 2 mm and 10 cm depth) enclosed in a muslin bag was put after the fine sand for the removal of some chemicals from the water. A diffuser plate using the Perspex glass (29.8 by 29.8 cm) with 2 mm perforations spaced 2 cm apart was placed on the filter chamber 15 cm away from granular carbon. The diffuser allows flow of water from the storage water tank to be spread over the entire sand filter bed. The outlet pipe (1.27 cm diameter and 15 cm long) for filtered water was fixed at 5 cm to the bottom of the filter chamber. The outlet pipe has a control tap for regulating the flow of clean water from the filter.

The exploded view of the laboratory slow sand water filter was shown in Figure 1 while the picture of the slow sand water filter was shown in Figure 2. The cost of component parts and the total cost of constructing a slow sand filter between April and May, 2017 using readily available materials in Ilorin was forty nine thousand sixty naira (N49,060) as shown in Table 1 of the Bill of Engineering Measurement and Evaluation or Bill of Quantity.

Performance evaluation of the slow sand filter and water qualities analysis: The flow rate of water through the slow sand filter was determined in order to estimate the capacity or the quantity of water which the filter could produce in litre per hour or litre day. A 1 litre glass measuring cylinder was put at the outlet of the slow sand filter, the control tap of the storage tank was opened and the raw water flow from the tank into the filter chamber where the water was filtered by the granular carbon and sand particles. A stop watch was switched on immediately when water reaches the filter chamber and switched off when the cylinder was filled to 1 litre level. The flow rate (discharge) was determined using Equation (1). The average time taken by the water through the filter to fill 1 litre for three replications was 236 s. The water qualities analyses was conducted to determine the performance evaluation of the filter were some selected physical, chemical and bacteriological properties of the water before and after filtration. Clean and sterilized plastic bottles were used to collect water samples for the analysis. The physical, chemical and bacteriological properties of the water were determined using the standard method given by AOAC (2000).

$$Q = \frac{V}{T} \quad (1)$$

$$Q = \frac{1.00}{236} \times 60 \times 60 = 15.25 = 15.3 \text{ litres/h} = 0.0153 \text{ m}^3/\text{h}$$

Operating principles and maintenance of the slow sand filter: Quantity of raw water (like 30 litres) to be filtered is poured into the storage tank of the filter and the control tap is opened for the water to flow into the filter chamber. It takes about 5 minutes for the raw water to flow through the filter bed. Pathogens, dissolved particles, turbidity and some chemicals would be removed from the water or reduced to acceptable level. When the outlet control tap is opened, clean water would flow through the outlet and the water is collected from the outlet. Slow sand filter does not need electricity to power its operation. The slow sand filter is suitable for teaching and does not require operating cost. Maintenance of the slow sand filter is required after it has been used continuously for water filtration and observed that water could not flow through the filter due to blockage of the pores of the filter bed by accumulation of dirty particles. The maintenance is done by removing about 3 to 5 cm depth of the fine sand from the top layer and refill with new fine sand.

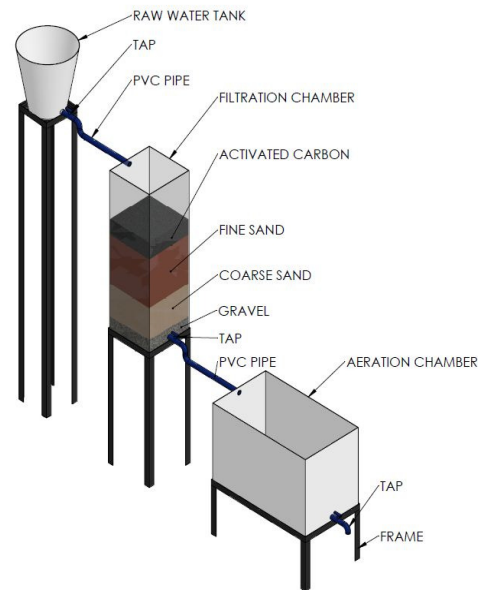


Fig 1: Exploded view of the sow sand filter.

RESULTS AND DISCUSSION

The slow sand filter has a capacity of producing 15.25 litres/h of clean water that is safe for consumption without causing .diseases to man. The results of physical, chemical and bacteriological properties of the water obtained from the filtered and non-filtered water (raw water) 4 days after the construction of the filter when the biofilm layer (*schmutzdecke*) has not developed was shown in Table 2. The filter reduced the turbidity by 86.42% from 6.7 NTU for non-filtered (raw water) to 0.91 NTU after passing through the filter.

Table 1: Bill of Engineering Measurement and Evaluation (BEME) for the slow sand filter as at April –May, 2017

S/No	Item	Description	Quantity	Rate (₦)	Amount (₦)
1	50 litres plastic bucket	Storage tank for raw water container	1	1,500	1,500
2	20 litres Plastic bucket with lid	Filtered water container	1	600	600
3	4 mm thick Perspex glass (120 by50 cm)	Construction of the filter chamber	1	22,000	22,000
4	Metal control tap	Raw water outlet	1	600	600
5	Plastic Control tap	Filtered water outlet	1	400	400
6	Wooden stand	Stood for storage tank	-	-	3,500
7	PVC Pipe (1 inch)	Outlet raw water pipe	1	500	500
8	PVC Pipe (1/2 inch)	Outlet clean water pipe	1	500	500
9	Granular Carbon	Carbon and Membrane	-	700	700
10	Silicon gum	Sealant gum for pipe connection	-	700	700
11	Bulkhead fitting	Draining of dirty water	1	500	500
12	Tigre elbow	Elbow join connection	1	-	60
13	Labour cost	Pipe fittings and Filter chamber construction	-	-	17,500
Total		-	-	-	49,060

This was in agreement with the study of Bagundol *et al.* (2013) that slow sand filter reduced turbidity of well water by 99% with depths of sand filter medium varied from 30 -90 cm. Effect of the slow sand filter on some selected chemical properties of water. The slow sand filter also reduced the concentrations of Calcium, Magnesium, Potassium, Sodium and Iron in the water as shown in Table 2. The concentration of iron in the raw water (0.6 mg/l) was initially above water quality limits of SON (2007) but reduced below the limits after passing through the filter. The granular carbon has ability to remove some chemicals in water because is an adsorbent agent. Effect of slow sand filter on the removal bacteriological property (pathogens) of water was not 100%. The E-Coli count present in the non-filtered water (water before filtration) was 13 but the E-Coli count reduced to 4 after passing through the filter. The filter slow sand filter reduced the E-Coli present in the water by 69% but could not totally remove the E-Coli from the water as shown in Table 2 because biofilm layer had not developed within 4 days. Buzunis (1995) pointed out

that biofilm layer (schmutzdecke) normally develops 2 – 3 weeks after the construction of the slow sand filter and the filter bed must be kept wet. Even when the biofilm layer has fully developed, most slow sand filters could not totally (100%) remove pathogens from the water contaminated by pathogens. Bagundol *et al.* (2013) reported that the efficiency of E-Coli removal by slow sand filter depends on the depth of the sand filter media, biofilm layer and flow rate of water through the filter but the slow sand filter could not totally remove E-Coli by 100%. This means that after the filtration of water in the water treatment plant, disinfectant like chlorine (chlorination) is normally added to kill the pathogens so that the water is 100% safe for consumption. From this study, undergraduate students should know that most slow sand filters could not totally (100%) remove pathogens in the contaminated water. The filter had positive effect in the removal of turbidity, colour, electrical conductivity, removal of some chemicals and reduced the E-coli contents of microorganisms.

Table 2: Physical, chemical and bacteriological parameters of water after passing through the slow sand filter

Parameter	Non-filtered water	Filtered water	SON Acts 2007
Taste	Mild	Tasteless	Tasteless
Turbidity (NTU)	6.7	0.91	5.0
(BOD)	5.6	0.9	-
Colour (TCU)	10	6.8	15
pH	7.2	6.7	6.5-8.5
EC μ S/cm	83.7	26.8	1000
Ca ²⁺ (mg/l)	28.0	12.6	200
Mg ²⁺ (mg/l)	20.0	16.0	0.20
K ⁺ (mg/l)	0.72	0.31	-
Na ⁺ (mg/l)	1.63	0.82	200
Hardness (CaCO ₃) (mg/l)	48.2	15.8	150
Iron (mg/l)	0.65	0.12	0.30
Colonies/100ml growing on nutrient agent at 37°C in 24hours	40	12	-
E-Coli cfu/100ml	13	4	0
Salmoneth cfu/100ml	Nil	Nil	0

SON = Standard Organisation of Nigeria Act 2007 for drinking water quality

Conclusion: The laboratory slow sand filter was fabricated from locally available materials mainly

transparent perspex glass, freely running sand, plastic bucket and PVC pipe. The filter reduced the turbidity

by 86.42% and reduced the some chemicals in the water to water quality limits. The slow sand filter in this study reduced E-Coli count by 69%. The filter and most other slow sand filters could not totally remove faecal coliform and pathogens from the water in order to make high contaminated water by pathogens safe for consumption. It is recommended that the slow sand filter should be used for purification of water in the laboratory for teaching and disinfectant must be added to the water after filtration to kill all the pathogens because most slow sand filters could not totally remove some of the deadly pathogens in the contaminated water.

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