

A SIMPLE SLOW-SAND FILTER FOR DRINKING WATER PURIFICATION

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Abstract

Water-borne diseases are commonly encountered when pathogen-contaminated water is consumed. In rural areas, water is usually obtained from ponds, open shallow wells, streams and rain water during rainy season. Rain water is often contaminated by pathogens due to unhygienic of physical and chemical conditions of the roofs thereby making it unsafe for consumption. A simple slow sand filter mechanism was designed and fabricated for purification of water in rural areas where electricity is not available to power water purification devices. Rain water samples were collected from aluminum roof, galvanized roof and thatched roof. The waters samples were allowed to flow through the slow sand filter. The values of turbidity, total dissolved solids, calcium, nitrite, faecal coliform and total coliform from unfiltered water through thatched roof were 0.92 NTU, 27.23 mg/l, 6 mg/l, 0.16 mg/l, 5cfu/100ml and 6.0 cfu/100ml, respectively while the corresponding values for slow sand filter from thatched roof were 0.01 NTU, 0.23 mg/l, 2.5 mg/l, 0.1 mg/l, 0 cfu/100ml and 0 cfu/100ml, respectively. The values of turbidity, total dissolved solid, nitrite, calcium, faecal coliform and total coliform from unfiltered water for aluminum roof were 0.82 NTU, 23.68 mg/l, 2.70 mg/l, 1.0 mg/l, 4 cfu/100ml and 4cfu/100ml, respectively while the corresponding values for slow sand filter were 0.01 NTU, 0.16 mg/l, 0.57 mg/l, 0.2 mg/l, 0 cfu/100ml and 0 cfu/100ml, respectively. The values obtained for galvanized roof were also satisfactory. The slow sand filter is recommended for used in rural areas for water purification to prevent risk of water-borne diseases.

Keywords: potable water, rainwater, slow sand filter, water purification, water quality

1. Introduction

Rainwater is natural potable water but it is usually contaminated on the roof by dirt, insects and bacteria that could cause certain diseases to man. The levels of contamination of rainwater with pathogenic organisms depend on the condition and type of roof from which rainwater is collected through which man could get water-borne diseases such as typhoid, cholera, dysentery and some other diseases (Hammer and Hammer, 2012). Thus, there is a need to subject all drinking water to purification processes before consumption to ensure public safety. Wirojanagud *et al.* (1998) pointed out that rainwater is a natural potable water that has better quality than most of other sources of water in many countries but it can be contaminated with pathogens during handling services.

Different potable water purification devices are available but some of them needed electricity to power its operation. A relatively cheap slow sand filter also called bio-sand filter or biological sand filter is used for water purification and does not require electric power for its operation. It can be used in rural areas for water purification. The slow sand filter uses the filtration method to remove dissolved particles and microorganisms (Basak, 2003, Chatterjee, 2007 Simpson, 2008, Hammer and Hammer, 2012). Basak (2003) also pointed out that the slow sand filter can considerably improved the chemical, physical and biological properties of water when water is allowed to flow through it. WHO (1996) also indicated that the slow sand filter has a significant impact in reducing diseases cause by microorganisms because it can remove 98 to 99 % of microorganisms.

The direct old method of filtration uses white silk cloth to remove debris and particles but not effective for water purification because colour, odour, taste and chemical cannot be removed. Slow sand filter consists of sand, pea gravel and gravel layers as the filtering media and perforated drain plate inside the drum to support the filtering media for easy purification of water (Wirojanagud *et al.*, 1998). It is effective and inexpensive for water purification. Slow sand filter differs from other filters because it uses biological film or bio layer that grows naturally on the surface of the sand. The sand acts as a substrate upon which the biological film grows (Wirojanagud *et al.*, 1998). Biofilm (schmutzdecke) 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). Schmutzdecke is a gelatinous slime of biological matter that form on the surface and on the sand layer which act like a cake filtration medium in the slow sand filter. It consists of bacteria, fungi, protozoa, rotifer and some aquatic insect larvae (Alemayehu, 2012 and Shoemaker, 2014).

The biological mechanisms within the schmutzdecke are possible due to the absence of pre-disinfectant (Lahlou, 2000). The influent water is held in a 1 to 1.5 m water reservoir above the sand bed (supernatant also called top-water), whose primary function is to provide the pressure that carries water through the filter. As it moves downward, water enters the intensely active biofilm layer, where various microorganisms entrap, digest, and break down organic matter contained within (Shoemaker, 2014 and Visscher *et al.*, 1987). Visscher *et al.* (1987) recommended three layers for slow sand filter and also gave their sizes and depths (thickness) which are coarse sand of diameter 1.0 – 1.4 mm, 100 mm thickness; gravel of diameter 4.0 – 5.6 mm, 100 mm thickness and gravel of diameter 16.0 – 23.0 mm, 150 mm thickness. Visscher *et al.* (1987) recommended a minimum depth of 0.6 m of filter media layer for purification of water by slow sand filter.

O'Toole *et al.* (2000) pointed out that several reasons are responsible for bacteria to form biofilms in a slow sand filter, but one important reason is the availability of nutrients at media surfaces. A filter is considered biologically active when there is no disinfectant in the filter influent. This lack of disinfection allows for microbial growth within the filter, which leads to a combined physical and biological treatment in a single process unit (Shoemaker, 2014).

Water flows slowly through the layers of sand and pea gravel of the filter bed. The slow sand filter reduces turbidity of water, and removes pathogens by biological action and filtration (Shoemaker, 2014). The slow sand filter drum can be constructed from galvanized iron sheet or polyvinyl chloride (PVC) material. World Health Organisation recommended that a non-reactive material such as plastic (PVC) and fiberglass could be used for the drum (WHO, 1996). The objectives of this study were to design, fabricate and determine the performance evaluation of a slow sand filter.

2. Materials and Methods

2.1 Materials used for Construction of the Slow Sand Filter

A slow sand filter was designed and fabricated using locally available materials in Ilorin. The materials were galvanized iron sheet, sand, pea gravel, PVC pipe and a tap. The filter basically consists of tank, water inlet pipe, supernatant (top water), filter sand bed (filter

media), drain plate, flow control outlet tap, drain pipe and the stand. The tank (drum) has a diameter of 0.3 m and 1.1 m high constructed from 2 mm thick galvanized iron sheet.

2.2 Design and Construction

The total capacity of the filter drum was determined to be 77.8 litres using Equation (1) (Alemayehu (2012)). The recommended rate of filtration (loading rate) through the filter bed is 0.1 to 0.2 m/h (Alemayehu (2012)). The rate of filtration through the filter bed having an area of 0.070695 m² was determined using Equation (2) given by Alemayehu (2012). The supernatant is the water reservoir space above the sand filter bed and it is the depth between the biofilm layer and top of the drum. 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 and for proper functioning of the slow sand filter. The supernatant for this water filter was 0.36 m.

The total depth of filter bed was 0.60 m which consists of uniform fine sand of 0.20 m deep (grain size of 0.25 mm), coarse sand 0.30 m (grain size of 0.35 mm) and pea gravel 0.10 m (grain size of 19.05 mm). The depth between drain pipe and the pea gravel was 0.15 m. The stand was 0.20 m high and was constructed using iron rod 25.4 mm diameter. The exploded view of the slow sand filter was shown in Figure 1 while the pictures of the slow sand filter is shown in Figures 2. The Bill of Engineering Measurement and Evaluation of constructing the filter in Ilorin as at April 2014 is shown in Table 1.

$$V = \frac{\pi d^2 h}{4} \quad (1)$$

$$V_R = \frac{Q}{A} \quad (2)$$

where: V is the volume of the slow sand filter tank (m³ = 10³ litres), d is the internal diameter of the slow sand filter tank (m), h is the height of the filter tank (m), π is 3.142, V_R is the velocity of water (filtration rate) through the filter m/h, Q is the discharge capacity of the water filter (m³/h) and A is the area of the filter bed in the filter drum (m).

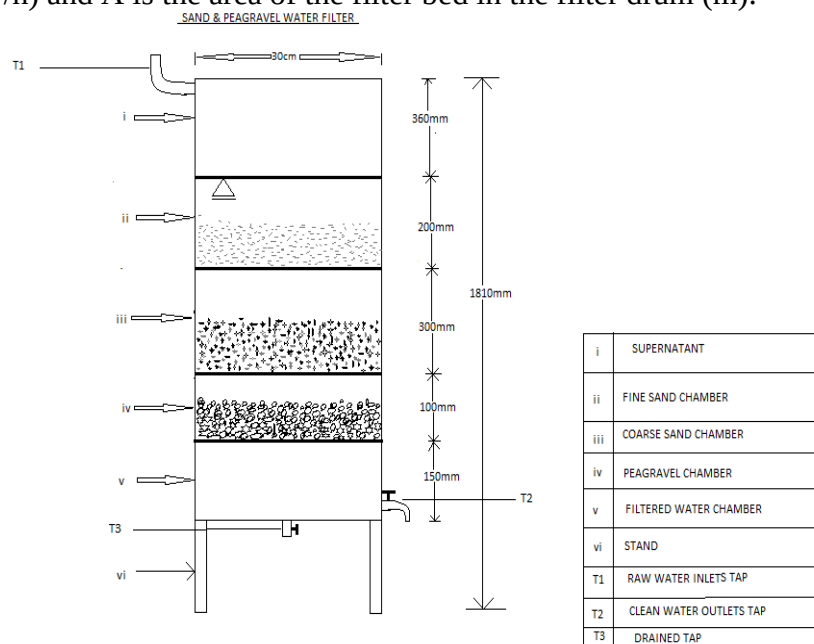


Figure 1: Schematic diagram of the sow-sand filter



Figure 2: The slow sand filter for water purification

Table 1: Bill of Engineering Measurement and Evaluation (BEME) as at April, 2014

S/N0	Material	Dimension	Quantity	Unit rate (N)	Cost (N)
1	2 mm thick galvanized sheet	-	1 sheet	12,500	12,500
2	Inlet socket connector	1 inch	1	250	250
3	Drain tap	$\frac{3}{4}$ inch	1	400	400
4	Water control outlet tap	$\frac{1}{2}$ inch	1	450	450
5	0.25 mm sand	-	5 kg	150	750
6	0.35 mm sand	-	5 kg	150	750
7	3.50 mm Pea gravel	-	5 kg	250	1,250
8	Electrode and Workmanship	-	-	-	2,500
Sub – Total					18,850
Contingency (10 % of Sub – Total)					1,885
Grand Total					20,735

2.3 Performance Evaluation of the Water Filter

Rain water samples were collected from aluminum, galvanized and thatched roofs. The collected water samples were subjected and some of their physical, chemical and bacteriological tests (properties) of water were determined using standard methods of the examination of water and wastewater by American Public Health Association (ALPA, 2005).

2.4 Maintenance of the slow sand filter

Water filter gradually loses its performance after it has been used continuously over a given period of time and this could be observed or characterized by reduction in the flow rate. This is as a result of blockage of the pores of the filter bed by the Schmutzdecke. The maintenance is by cleaning and scrapping the top layer of the filter sand and Schmutzdecke. Then, add water for few hours and new Schmutzdecke will develop on the sand filter layer in few days and the water filter can now be used for water purification (Alemayehu, 2012 and Shoemaker, 2014).

3. Results and Discussion

The fabricated slow sand filter has a capacity of producing potable water ranging from 5.0 to 10.0 l/h. The values of pH for water sample collected from thatched and galvanized iron roofs were 5.0 and 5.6 and corresponding values after filtering process through the water filter were

7.0 and 6.8, respectively. The means that the filter had increased (improved) the pH value of water from 5.0 to 7.0 for thatched roof and 5.6 to 6.8 for galvanized roof which is okay for consumption as shown in Table 2 because the recommended pH value by Standard Organisation of Nigeria (SON, 2007) for drinking water ranging from 6.5 – 8.5. The values of turbidity for aluminum, galvanized and thatched roofs before filtration were 0.82, 0.82 and 0.92 while after filtration through the water filter the values of turbidity were 0.01, 0.02 and 0.01 NTU, respectively. The total dissolved solids (TDS) for aluminum, galvanized and thatched roofs before filtration were 23.68, 24.67 and 27.23 mg/L while the corresponding values after filtration were 0.16, 0.02 and 0.23 mg/L, respectively.

The nature of roof affected the quality of rain water especially the thatched roof which could hold soil particles. The type and nature of roof affected the quality of rain water and this increased the pH, turbidity and TDS. The values of turbidity, TDS, calcium, magnesium, iron, zinc and nitrite were reduced after the water had passed through the slow sand filter. This was in agreement that slow sand filter improved the physical and chemical properties of water (Basak, 2003, Chatterjee, 2007 and Hammer and Hammer, 2012). The faecal coliform count from aluminum, galvanized and thatched roofs before filtration were 4, 3 and 5 but the faecal coliform count after filtration through the slow sand filter was 0 for all the three roofs. The water filter removed all the faecal coliforms (pathogens) from the contaminated rain water as shown in Table 2. The results of bacteriological test obtained in this study by subjecting rain water through the slow sand filter was in agreement with the research by WHO (1996) that slow sand filter could remove 98 to 99 % of microorganisms.

Table 2: Physical, chemical and bacteriological parameters of water after passing through slow sand filter and water without passing through slow sand filter (control)

Parameters	Water from aluminum roof		Water from galvanized roof		Water from thatched roof		SON Act 2007
	Control	Sand filter	Control	Sand filter	Control	Sand filter	
Turbidity (NTU)	0.82	0.01	0.82	0.02	0.92	0.01	5
Appearance	Slightly cloudy	Very clear	Slightly cloudy	Very clear	Cloudy	Clear	-
TDS (mg/l)	23.68	0.16	24.67	0.02	27.23	0.23	500
pH	6.8	7.8	5.6	6.8	5.0	7.0	6.5 – 8.5
EC (μ S/cm)	105.1	105.0	104.0	106.1	103.2	106.0	1000
Ca ²⁺ (mg/l)	2.70	0.57	2.50	2.00	6.10	2.50	200
Mg ²⁺ (mg/l)	-	-	3.30	2.30	2.81	2.00	0.20
Fe ²⁺ (mg/l)	-	-	1.86	0.01	1.70	0.01	0.30
Zn ²⁺ (mg/l)	-	-	1.04	0.22	-	-	3.00
Nitrite(NO ₂)mg/l	0.14	0.10	1.00	0.20	0.16	0.10	0.20
Faecal coliform (cuf/100ml)	4	0	3	0	5	0	0
Total coliform (cuf/100ml)	4	0	4	0	6	0	10

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

4. Conclusion

The slow sand filter was fabricated from locally available materials mainly galvanized sheet, fine sand, coarse sand and pea gravel. The filter reduced the TDS of rain water from 27.23 mg/l to 0.23 mg/l for thatched roof and it also increased the pH of the water from acidic medium of 5.0 to recommended value of 7.0. The water filter removed all the faecal coliform from the contaminated rain water.

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