Removal of *Escherichia coli* and other Contaminants in Wastewater Using Intermittent Sand Filtration

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Abstract
This study was aimed at determining the purification capacity of sand filtration under laboratory setting for the elimination of pathogenic bacteria, organic matter and suspended solids. The fate of Escherichia Coli (E. coli) load along the depth of the filter bed was also investigated using hydraulic loading rate of 0.185 m/day and synthetic wastewater of 172.3 mg/L of BOD_5*. Two columns of 50 and 100 cm filter depths were intermittently dosed for 14 weeks. Results show that the Intermittent sand filtration system (ISF) has high potential for removal of organic matter, suspended solids and oxidation of ammonium to nitrate-nitrogen. The average removal of* BOD_5 *was above 85%. Other contaminants such as TSS,* NH_4*-N and* PO_4*-P showed appreciable reduction, while* NO_3*-N increased due to the absence of anaerobic condition. E. coli abatement was 99.999% and 99.9987% respectively in 100 and 50 cm columns depth respectively. E. coli concentration after the experiment shows continuous decline along the filter bed.*

Keywords: *Intermittent filtration, microbes, purification, sand, wastewater.*

1.0 INTRODUCTION

The septic tank–soak away system is traditionally believed to be treatment system for domestic wastewater in most dwellings in Nigeria. The system can only be a treatment option where suitable soil conditions exist for the removal of organic carbon, phosphorous, ammonia-nitrogen, total suspended solids and microorganisms (Burke and Rodgers, 2010). High water table of coastal areas cannot support the use of the system. In water logged area, the construction of soak away is not feasible as the effluent from the septic tank will constitute a source of pollution to ground and surface water through the transportation of organic, inorganic and pathogenic organisms and result in environmental and health problems. Among the pathogenic bacteria that might be transported into groundwater are *Salmonella sp., shegella sp., Escherichia coli and vibrio sp.* This is due to the ability of pathogens to travel through porous media. Abu-Ashour et al. 1994 has reported that bacterial movement through soil is a rapid one which can lead to their high concentration reaching receiving waters. If pathogen contaminates groundwater, it can travel far away to become a non-point source of pollution that is difficult to treat compared to a point source.

Filtration is most commonly used to achieve supplemental removal of suspended solids (including particulate BOD) from wastewater after it has undergone some biological and chemical treatment processes as reported by Hamoda et al. (2004). It has been developed as a tertiary treatment method for secondary effluents in many arid regions where the treated water is used for irrigation and shallow groundwater recharge (Brissaud et al., 1989).

The process of intermittent sand filtration, which entails feeding and resting periods provide avenue for the renewal of oxygen into the medium by convection and molecular diffusion (Bancole et al., 2003).

Rodger et al. (2011) reported that the performance of an intermittent sand filter system will vary with the media used, temperature, hydraulic loading rate (HLR), organic loading rate (OLR) and method of application. The process and type of filtration being adopted dictate the sizing of the filter media to be used (USEPA, 1980; Loomis and Dow, 1999).

In a study of four sets of 3 identical sand filters with 0.38 m depth, effective grain sizes of 0.33, 0.54 and 0.93 mm, uniformity coefficient of less than 1.42, and HLR of 163 L/m^2-day, there was no discernible difference in performance results as reported by Darby et al. (1996).

The effectiveness of intermittent filters which comprises sand, soil and glass media in the treatment of low-strength wastewater was reported by Burke and Rodgers (2010). It was focused that OLR of 9.8 g COD/m^2-day and 0.65 m deep soil performed best in the removal of organic carbon, ammonium-N and bacteria.

This study entails the construction and operation of two sand filters with 50 and 100 cm depth to treat a synthetic wastewater similar to septic tank effluent strength for a period of 14 weeks. The aim was to determine the effectiveness of the sand filtration treatment system under laboratory setting using the elimination of pathogenic bacteria with *E. coli* as an indicator and reduction of organic matter and suspended solids as criteria.

2.0 MATERIALS AND METHOD

The study was conducted in the Granulometric Laboratory of Hydraulic Research Unit, Civil and Environmental Engineering Department, University of Lagos, Lagos. The laboratory set up consisted of two filter columns of perspex material. The diameter of the columns is 100 mm and it is 5 mm thick. The bases of the columns were sealed with flat perspex of 10 mm thickness. The filter sand was sourced from Ilaje, a suburb of Lagos. The characteristics of the filter material are as presented in Table 1. These values fall within those recommended by USEPA (1980).

For this experiment, *E. coli* was used as the indicator pathogen. The concentration of the *E. coli* in the range of 8.0 E+08 to 8.4 E+08 (cfu/100 mL) that met the effluent from the measured septic tank values was prepared. This was applied to the filter through the use of peristaltic pump. The pump was operated for 15 mins duration and rest for 3 hours 45 mins. for each batch at a hydraulic loading rate of 0.185 m^3/m^2.d^{-1}. The batching was 6 times per day for 14 weeks.

The influent was sampled daily while the effluent was sampled every 4 hours thus totaling 6 effluent samples for laboratory analysis every day. The water quality parameters tested for were: BOD_5, NH_4-N, NO_3-N, PO_4-P and *E. coli*. The BOD_5 was tested for in accordance with the 5-day BOD test method. The NH_4-N, NO_3-N, and PO_4-P were analysed using HI 83099 COD and multi parameter bench photometer. All water parameters were analyzed using standard methods (APHA, 2005).

Table 1: Granulometric and hydraulic characteristics of filter materials

Parameter	Value
d_{10}	0.42 mm
d_{15}	0.47 mm
d_{60}	0.92 mm
d_{75}	1.3 mm
Cu	2.2
Effective pore diameter$\left(\frac{d_{15}}{5}\right)$	0.094 mm
Hydraulic Conductivity, K	4.632×10^{-3} m/s
Bulk Density	1701 kg/m^3

The fate of *E. coli* with filter column depth was investigated upon the dismantling of the columns. At every 10 cm and 20 cm layer below the surface of the 50 and 100 cm filter depth respectively, samples were collected and analyzed.

3.0 RESULTS AND DISCUSSION

The summary of obtained results is as presented on Tables 2 and 3. The average BOD_5 of the influents into the columns was 172.3 mg/l. In the two columns, the removal of BOD_5 was very effective in the sand filter. The initial BOD_5 of 172.3 mg/L was reduced to 25.4 and 25.6 mg/l in the 100 and 50 cm filter column respectively. These translate to removal efficiency of 85.25 and 85.14% in the columns respectively as shown in Table 3.

Table 2: Characteristics of influent wastewater

Parameters	Average Influent value	Standard Deviation	Range	No. of samples
BOD_5	172.3	16.7	216 – 152.8	84
NO_3	1.8	0.1	1.95 – 1.6	84
NH_4-N	12.62	1.65	14.68 – 8.29	84
PO_4	2.9	0.65	4.2 – 2.2	84
TSS	14	2	17.5 – 12.6	84
E. coli	8.4 E+08	8.0 E+08	8.62 – 7.9 E+08	36

All parameters in mg/l excepts *E. coli* in cfu/100 ml

The result shows that the organic loading removal by filter is not strongly dependent on the depth of the filter media; this is in agreement with Amador et al. (2008) and Wilson et al. (2011).

Table 3: Characteristics of the purified water

Parameters	Average		Std. Dev		Range		Removal (%)	
	100 cm	50 cm	100 cm	50 cm	100 cm	50 Cm	100 cm	50 cm
BOD_5	25.4	25.6	1.5	1.5	27.8-23	28-23	85.25	85.14
NO_3 -N	20.7	19.5	6	5	26-3	24-5	N.A	N.A
NH_4-N	0.70	1.31	0.44	0.17	1.62-0.22	1.62-1.08	86.41	89.36
PO_4 -P	1.34	1.57	0.5	0.4	1.95-0.85	2.1-1.1	45.8	53.4
TSS	2.1	2.98	0.9	1.07	4.1-1.1	5-1.6	87.86	86.71
E. Coli	2.98 E+05	2.78 E+05	3.1 E+05	2.85 E+05	5.7-4.3 E+05	5.94-0 E+05	99.999	99.9987

All parameters in mg/l excepts *E. coli* in cfu/100 ml

The removal efficiencies of BOD_5, TSS and ammonium in the experiment were in the range of 85 to 99%. This does not apply to the removal of phosphorus (PO_4-P) that has the removal efficiencies of 45.8 and 53.4% in 100 and 50cm filter depth respectively. The percentage removal efficiencies of PO_4-P agreed with Bali et al. (2011) but lower than the 95 and 99% reported by Hu et al. (2011) and Achak et al. (2009).

The biological removal of nitrogen is a two-step process of nitrification and denitrification. During nitrification, a decrease in NH_4-N levels was noticed follow by an increase in NO_3-N concentration. Metcalf and Eddy (2003) reported that nitrification occurs at optimum pH values of 7 and 8. The removal of ammonium nitrogen reached 86.41 and 89.36% respectively in the 100 and 50 cm filter columns. According to Limin et al. (2009), NH_4-N removal is by combination of biodegradation, adsorption and filtration mechanisms. The observed reductions in NH_4-N from the column experiment agree with results obtained in similar experiment by Rodger et al. (2011).

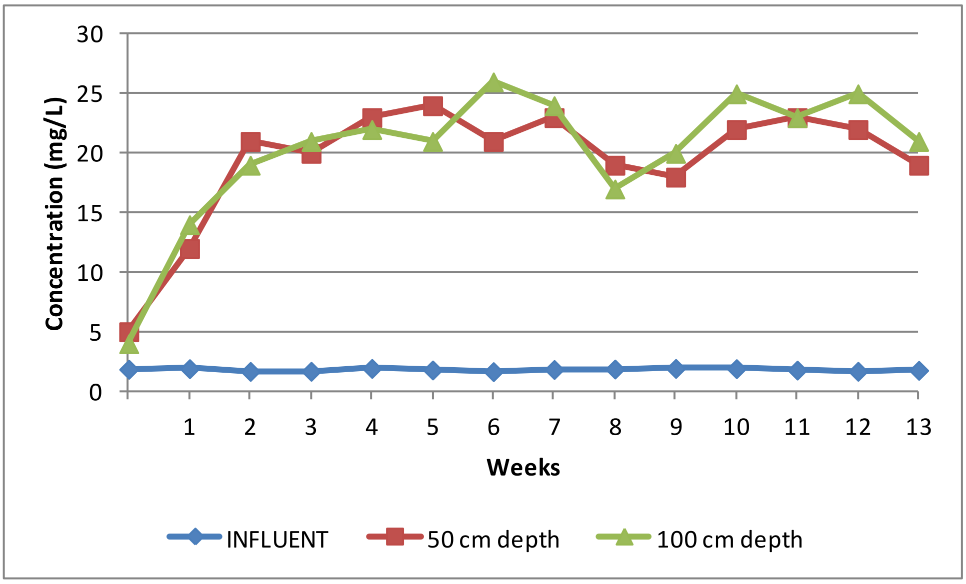

Figure 1: NO_3-N values as a function of time

The nitrification process was high and led to the high production of nitrate. The production of nitrate increases with depth in the filter columns due to aeration along the filter depth. As reported by Bali et al. (2011), the significant increase in the nitrate concentration could be attributed to the conversion of organic form of nitrogen to nitrate form due to oxidation reactions during the treatment process. The slightly higher value of nitrate in the 100 cm filter depth was an indication of oxidation process being continuous along the depth. Principally, there is no significant difference in NO_3-N levels between the depths as shown in Figure 1. This agrees with Amador et al. (2008). The effluent's nitrate value was higher than the influent due to the absence of anoxic condition in the filter that could have denitrified the nitrate to nitrogen gas.

3.1 Purification Capacity

The performance of filtration mechanism depends on its ability to remove microorganism from the water. This was performed by measurement of the micro organism in the applied wastewater to the columns and the filtered water from the columns. The average concentration of the *E. coli* in the wastewater was 8.4 E+08 (cfu/100ml). In the filtered water, the measured *E. coli* were 2.98±3.1 E+05 and 2.78±2.85 E+05 (cfu/100mL) from 100 cm and 50 cm columns respectively. This translates to reduction of about 3 cfu/100 ml of *E. coli* with a percentage removal of 99.999 and 99.998 respectively in 100 and 50 cm filter depth.

3.2 *E. coli* Fate and Movement in Filter Bed

On completion of the experiment, the examination of the fate of microbes along the filter depth was examined. Samples of the filter were taken at 100 and 200 mm layers from 50 and 100 cm filters respectively. The average *E. coli* applied on the surface of the filters was 8.4 E+08 cfu/100ml.The result as shown in Table 4 revealed that the retained *E. coli* on the surface of 100 and 50 cm filter depth were 7.78E+08 and 7.65E+08 cfu/100ml respectively. Figure 2 show the quantity of the *E. coli* along the filter depth and revealed the reduction of *E. coli* with depth. Between 30 cm and 400 cm depth, 60% of *E. coli* reduction was recorded indicating that, this depth is very vital in the treatment of the wastewater. This is attributed to straining and availability of atmospheric air which makes the *E. coli* more active in this zone for digestion of organic nutrients and lead to multiplication of the *E. coli*.

Table 4: *E. coli* concentration in the column

S/N	100 cm Depth		50 cm Depth	
	Depth (cm)	*E. coli* (cfu/100ml	Depth (cm)	*E. coli* (cfu/100ml
1	0	7.78 E+08	0	7.65 E+08
2	-20	7.09 E+08	- 10	7.3 E+08
3	-40	6.7 E+08	-20	6.9 E+08
4	-60	5.9 E+08	-30	6.7 E+08
5	-80	5.25 E+08	-40	5.9 E+08
6	-100	5.07 E+08	-50	5.57 E+08

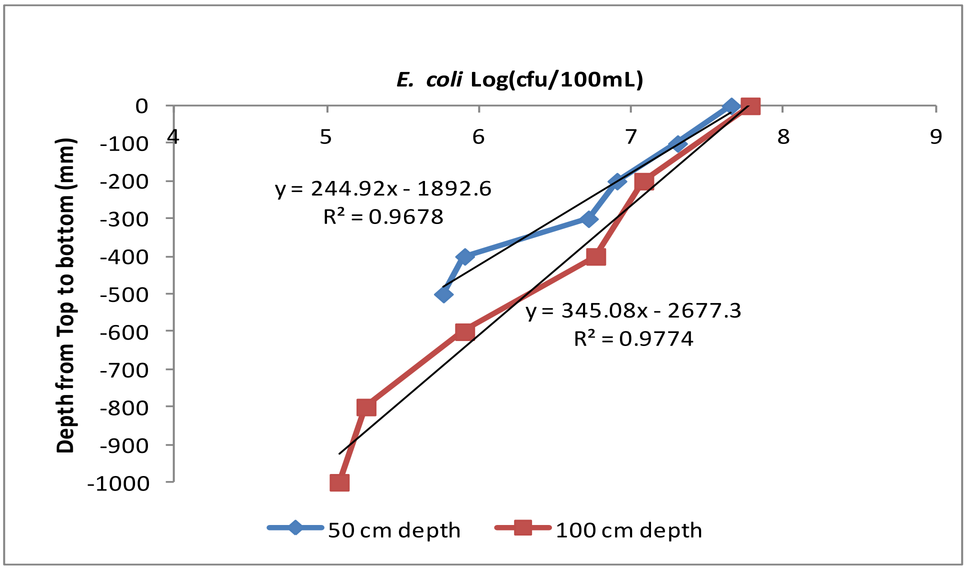

Figure 2: Fate of *E. coli* along the depth of filter columns

4.0 CONCLUSION

The results showed high performance in BOD_5, TSS and NH_4-N removal due to aerobic condition in the sand filter. The removal of PO_4-P was low compared with other parameters. The 99.999% abatement of *E. coli* shows that intermittent sand filtration technique is good for tertiary treatment of effluent from conventional septic tank. In areas of high water table and/or high porosity profile, this technique can be adopted. The reuse of this treated water is economically viable option in areas where water scarcity is prominent.

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Abbreviations and Acronyms

APHA	American Public Health Association
HLR	hydraulic loading rate
ISF	Intermittent sand filtration system
OLR	organic loading rate
TSS	Total Suspended Solid
USEPA	United State Environmental Protection Agency

BOD_5	Biochemical Oxygen Demand in 5th day
Cu	Coefficient of uniformity
COD	Chemical Oxygen Demand
d_{10}	Particle size that 10% of the material is finer than the rest
d_{15}	Particle size that 15% of the material is finer than the rest
d_{60}	Particle size that 60% of the material is finer than the rest
d_{75}	Particle size that 75% of the material is finer than the rest
E. coli	*Escherichina coli*
K	Hydraulic Conductivity
NH_4-N	Ammonium nitrate
NO_3-N	Nitrate nitrogen
PO_4-P	Phosphate
Std. Dev.	Standard Deviation