Stratified Saturated Control of Bacteria Migration in Porous Media: An Experimental Investigation

J. A. Adegoke*, A. A. Ogunjobi and T.A. Lateef*****

**Department of Physics, University of Ibadan, Ibadan. **Department of Microbiology, University of Ibadan, Ibadan. ***Department of Physics, Ekiti State University, Ado – Ekiti.*

****Corresponding Author e-mail: lattaof@yahoo.com*

UNIVERSITY OF IBADAN LIBRARY

ABSTRACT

The importance of sand bed filters has gained more ground in on- site water treatment facilities. The performance of which depends on the design of the sand bed. A laboratory column experiment was designed to quantitatively determine the best kind of sand layered arrangement for maximal bacteria attenuation. Porosity was taken as media parameter to further examine the relationship between the layers that will yield a better performance. Porosity was determined using volumetric approach and vertical downward flow for the column filtration. Escherichia coli and Staphylococcus aureus was used as contaminants. The results revealed that the larger the difference in porosity of the layers the better the filter performance and that least porous material should be below followed by the larger one arranged in the direction of flow. It was also shown that for homogeneous layered media, the more the number of layers, the better is the filter performance. These inferences would help in better design of stratified sand filter systems both for water purification and fishpond effluents treatment systems.

KEYWORDS: Bacteria, Porosity, Attenuation, Migration, Filtration

INTRODUCTION

The occurrence and transport of human enteric viruses and bacteria in and through groundwater have been a long-standing public concern (Roger et al., 1997). Waterborne diseases are significant public health issue and many originate from contact with human fecal material (Dick et al., 2005). The United States Environmental Protection Agency (USEPA, 2000) Science Advisory Board concluded that microbiological contaminants (bacteria, viruses and protozoa) were likely the greatest remaining health risk management challenge for drinking water supplies. The groundwater rule recognizes that the capacity for aquifers to remove microbiological contaminants from groundwater may not be adequate to protect public health and requires groundwater suppliers to achieve a 99.99% inactivation (loss of virulence) or removal of viruses, bacteria; if groundwater is to be supplied without treatment (Raymond, 2003). Despite the increase in the use of sand filter in water purification system; there is still a need to further the development in the design of such filtration system. Olusegun, (2004) investigated possible contamination of treated and untreated groundwater by fecal coliform and Escherichia coli in one hundred selected boreholes from different part of Ibadan metropolis in south-west, Nigeria and observed that 73% of the boreholes water samples had coliform with 18% having detectable E-coli and one sachet water contain coliform bacteria. Also, discoveries of exotic diseases on fish farm can trigger huge financial losses associated with state and federal quarantine and fish eradication (Jo Saddler and Andrew, 2007). Poor quality of water in fish pond cause diseases such as fin rot, white spot, ulcers, slimy skin and lesions which are caused by bacteria and viruses. Most African developing countries, Nigeria inclusive, presently import filter sand from Europe and other developed countries for local use in water treatment plants (Adewumi et al., 2004). This is due to lack of adequate research work on the usefulness of local sand for such application. Proper design of filter systems has the capacity to significantly reduce effluent concentrations of pathogenic microorganisms in wastewater treatment system and rapid sand filtration systems use in fish ponds. This will reduce the cost of fish production by improving the quality of water in fish pond through recycling with a better design sand filter and reduce the cost of water treatment using other forms of water purification like ultraviolet radiation if passed through well design sand filter to lower the bacterial load on such systems.

Smith et al., 1985 concluded that the transport of bacteria through sieved or mixed sand columns will be negligible when compared to more structured soil. Fonte et al., 1991 examined the effect of grain size, soil heterogeneity, and cell size on bacterial transport in column experiment. The results indicated that even in cases with efficient filtration, bacterial transport was significant. A graded filter serves better: it consists of layers of porous materials of different porosities (layered) (Cedergreen, 1976).

The objective of this work was to examine the effects of soil physical heterogeneity (media layering) on soil attenuation of bacteria movement through porous media under natural condition and to determine the best arrangement of layered media for maximal bacteria attenuation using downward flow through column. This would help in developing a quantitative understanding of the process involved and provide a better method to assist engineers in designing effective sand filter systems for water treatment both at home and in fishpond. The bacteria used was Escherichia coli (E -coli) –a rod and gram negative organism and Staphylococcus aureus- cocci and gram positive organism.

UNIVERSITY OF IBADAN LIBRARY

MATERIALS AND METHODS

Samples collection

Sand samples were collected from the river bed in Osun state, one from Osun-river along Iwo – Gbongan road and the other from water work dam in Iwo. Sizeable sand quantities were brought to the laboratory in polythene bags, washed with deionised water in order to remove fine organic materials that were in the process of decaying as a result of the work of soil micro organism. The samples were then boiled in 1M hydrochloric acid for 2 hrs and latter treated with 1M of NaOH (Adegoke et al., 2012) to remove metallic oxide coating on the sand and equilibrate the pH respectively. The resulting sand samples were washed again in deionised water, sundried and stony pebbles were removed. Sieve analysis was conducted using electric shaker. The mesh sizes used were 150µmm, 212µm, 300µm, 425µm and 600µm and labeled A, B, C, D, and E respectively. Porosity of the samples was determined using volumetric approach.

Bacteria Preparation and filtration experiment

Escherichia coli and *Staphylococcus aureus* isolates were collected from the Environmental Microbiology Unit laboratory, University of Ibadan. Pure culture was picked from slant with sterile wire loop and inoculated into sterile nutrient agar. The bacterial cells were then harvested. 1ml of the suspension was serially diluted and plated out to know the colony forming unit (cfu/ml). Glass column (1m long, 2.79 x10^{-2}m diameter) Pyrex were washed and disinfected with 70% ethanol and sterilized in hot air oven at 120^{o}C for 2 hours. Sand of different porosities was packed in layer of 10cm each into the column. For two layers, depth equal 20cm while for three layers is 30cm. For each of the layering experiment, the reversal was done. That is, the sand particle at the bottom was exchanged for the one at the top and vice versa (ascending and descending order of porosity). This was done to determine the order of arrangement of layers and difference in porosity suitable for two layers.

2ml of bacteria suspension of known concentration was dropped onto the sand bed in the column with the aid of 5ml sterile syringe and this was followed by intermittent supply of bacteria-free water (sterile). The effluents of the column was collected and analyzed for the bacteria load. 1 ml of the each effluent sample was serially diluted up to 10^{-5} and poured into sterile plate.

Order of layering: Two samples taking logically were arranged in ascending and descending order of magnitude of their porosity. The orders are as follows: A and E, B and C, and D and E. The same was done for three layers for homogeneous layering, the order of arrangement are BCD and DCB.

RESULTS AND DISCUSSION

Table 1 shows the experimentally determined values of porosity for each sample. The porosity ranged between 0.28 and 0.42 with sample A the least and sample E the highest. Tables 2 and 3 show the results of relative concentration recovery for five drains for Escherichia coli and Staphylococcus Aureus respectively.

Table 1: Determined values of porosity for the samples

Samples	A	B	C	D	E
Porosity(ϕ)	0.280	0.360	0.370	0.400	0.420

Table 2: Normalized value of concentration of five effluents collected for two layer in ascending (EA) and descending (AE) order of porosities (Escherichia coli)

No/ drains	C/Co: EA	C/Co: AE	C/Co: CB	C/Co: BC	C/Co: ED	C/Co: DE
1	0.1286	0.7714	0.3925	0.7383	0.2919	0.6541
2	0.1286	0.8286	0.5981	0.6075	0.3135	0.6378
3	0.3857	0.9000	**0.6355**	**0.4953**	0.3676	0.5730
4	0.3286	0.8714	**0.4860**	**0.4673**	0.4108	0.5297
5	0.2572	0.7143	**0.4766**	**0.4112**	0.3622	0.4108

UNIVERSITY OF IBADAN LIBRARY

Table 3: Normalized value of concentration of five effluents collected for two layer in ascending (EA) and descending (AE) order of porosities (Staphylococcus Aureus)

No/ drains	C/Co: EA	C/Co: AE	C/Co: CB	C/Co: BC	C/Co: ED	C/Co: DE
1	0.2898	0.8296	0.2500	0.3691	0.1989	0.8466
2	0.2727	0.8125	0.2500	0.3274	0.1761	0.7386
3	0.3296	0.7898	0.3058	0.3393	0.2784	0.6193
4	0.4091	0.6761	0.2857	0.2976	0.2500	0.7159
5	0.3921	0.6080	0.2738	0.2917	0.2273	0.6250

Note: *Ascending and descending order of porosities in the direction of flow*

Two layers: The recovery of Escherichia coli for two layers of sand at 10.00 cm each for sample of porosity ratio 1.500 and 0.667 (0.28 and 0.42 and its inverse) are shown in figure 1 (a); porosity ratio 1.028 and 0.973 (0.36 and 0.37 and its inverse) in figure 1 (b) and figure 1 (c) for 1.050 and 0.952 (0.40 and 0.42 and its inverse). Also, figure 1 (d,e,f) showed the recovery of bacteria at various drains for Staphylococcus aureus at same porosity ratio considered for Escherichia coli. From both figures, it is clearly revealed that one of the highest porosity ratio gives the best attenuation capacity. Figure 1 (b) and (e) revealed a distinct result, despite the fact that it follows the same trends with other, there was closeness in their rate of recovery, and this might be as a result of proximity of the sample porosity, the squared area that were bold showed a kind of reversal in recovery. This showed an importance outcome of variances in hydraulic conductivity as a result of variation in porosity; we note a sharp deflection when the different in porosities is very large (high porosity ratio) than when close (low porosity ratio), this subsequently increase rate at which bacteria are trapped at sharp boundary thus produce high attenuation. From this, we observed that as porosity ratio increases, the attenuation capacity of stratified layer media increases. From 1 (a), the percentage reduction of ratio A/E is 18.29% while its inverse E/A is 75.43%. In 1 (b) percentages reduction of B/C is 45.61% while its inverse(C/B) is 48.20%. Also, in (c) percentage reduction for D/E is 43.89% while is 65.08% for its inverse (E/D). For Staphylococcus aureus, A/E is 25.68% while it's inverse (E/A) was 77.39%, in B/C, the percentage reduction was 67.50% while its inverse (C/B) is 72.74%; and in D/E reduction is 29.09% and its inverse (E/D) is 66.14%. We confirmed that when using stratifying media, the medium with low porosity should be below followed by the one of higher porosity; and the larger the difference in the porosity, the better the performance of the stratified layers; and the better the filter it produces.

UNIVERSITY OF IBADAN LIBRARY

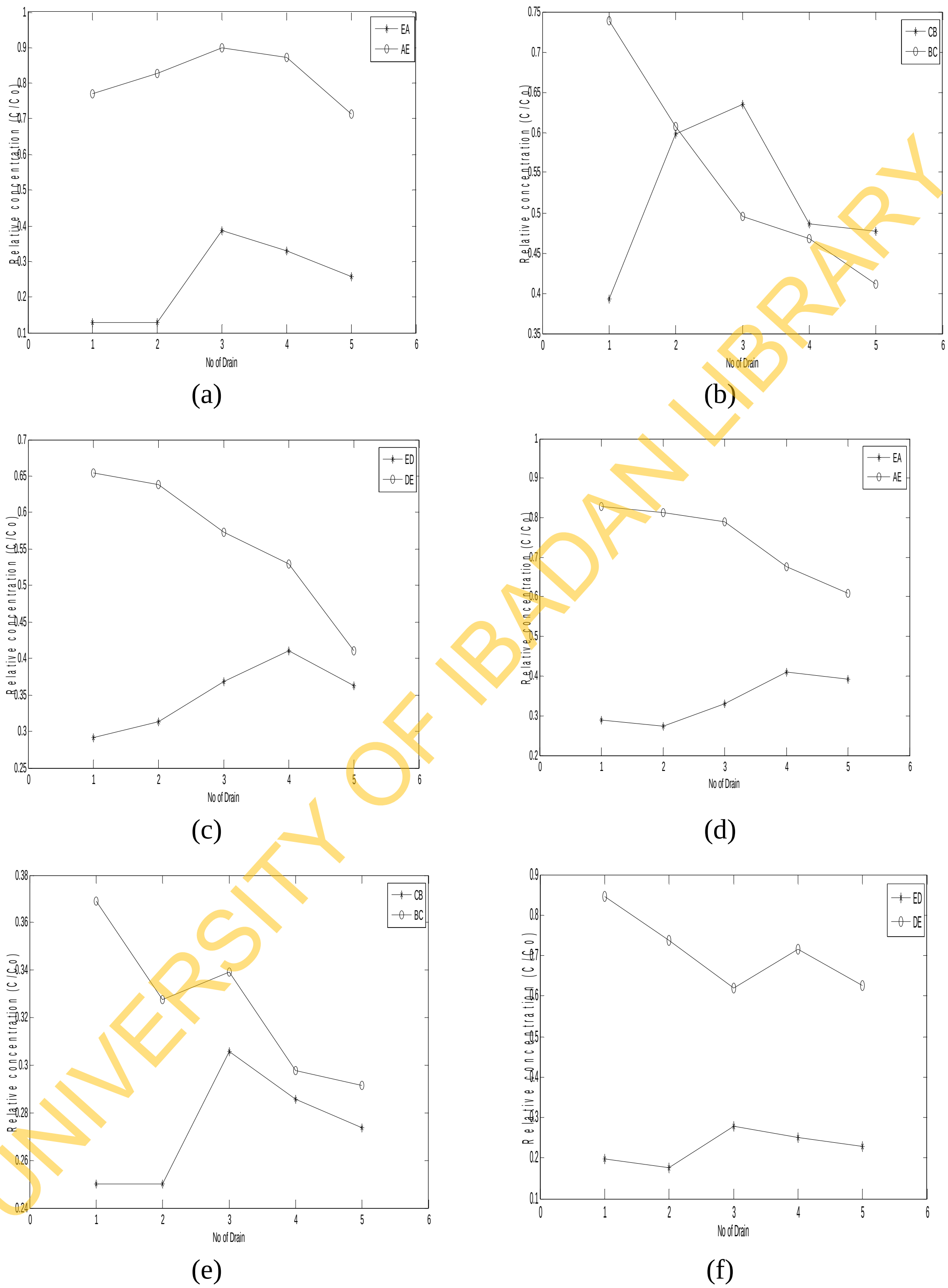


Figure 1: Relative concentration recovery versus number of drains for ascending (EA) and descending (AE) order of arrangement for both Escherichia coli (a,b,c) and Staphylococcus Aureus (d,e,f) respectively.

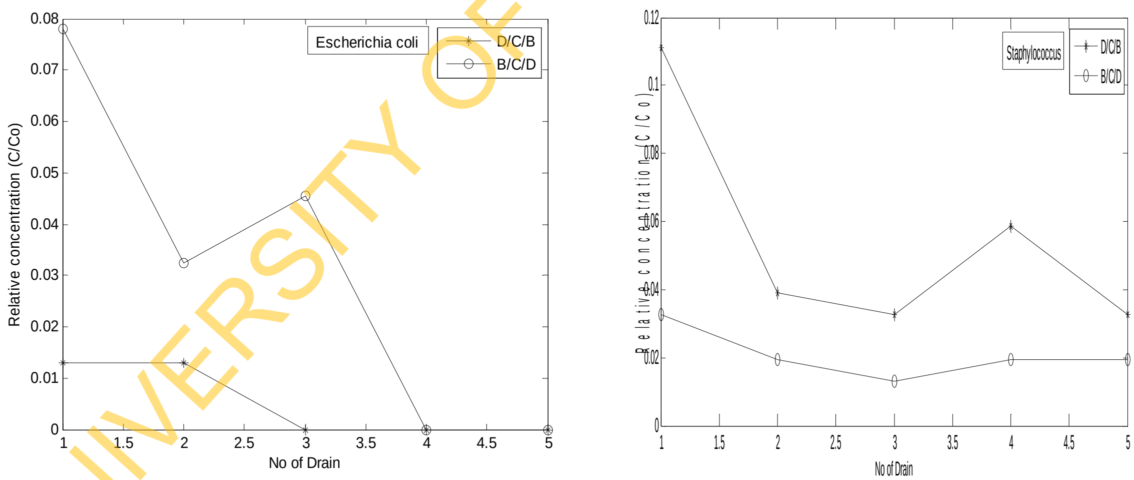
UNIVERSITY OF IBADAN LIBRARY

Three layers: the results of three layers in (D/C/B) and (B/C/D) are shown in the Table 4 below for Escherichia coli and Staphylococcus Aureus. Figure 2 showed the plot of relative concentration and number of drains.

Table 4: Normalized value for concentration of 3 layers using sorted media (10 cm each)

No of Drains	C/C_o : D/C/B (Escherichia coli)	C/C_o : B/C/D (Escherichia coli)	C/C_o : D/C/B (Staphylococcus)	C/C_o : B/C/D (Staphylococcus)
1	0.0130	0.0779	0.1111	0.0327
2	0.0130	0.0325	0.0392	0.0196
3	0.0000	0.0455	0.0327	0.0131
4	0.0000	0.0000	0.0588	0.0196
5	0.0000	0.0000	0.0327	0.0196

In terms of number of layers, further column experiment were carried out on the use of three layers of different porosity both in ascending and descending order. Figure 2(a) and (b) showed three layers of homogeneous media (physical heterogeneity) for Escherichia coli and Staphylococcus Aureus respectively. In figure 2(a), there was a percentage reduction of 96.88% for B/C/D while its inverse D/C/B was 99.48% for Escherichia coli; and figure 2(b) for Staphylococcus, percentage reduction is 97.91% for B/C/D and its inverse D/C/B was 94.51%. The behavior of the two bacterial were non uniform in three layers compared with two, it was concluded that presence of cell morphology is significant when filter system contains more than two layers. Variation in the physical heterogeneity not only non uniformity of bacterial migration in filter systems but also complicates the use of modeling in characterizing the use of sand media as hydrogeological barrier against pathogenic microorganisms into groundwater supplies source.



(a) (b)

Figure 2: Relative concentration recovery versus number of drains for three layers for Escherichia coli (a) and Staphylococcus Aureus (b)

UNIVERSITY OF IBADAN LIBRARY

CONCLUSION

In conclusion, the results presented in this paper demonstrated that stratified layering of the filter media is good mode of improving the performances of water filtration systems. The research work afford us to determine quantitative relationship that would yield high filtering capacity and attenuating capacity, hence higher degree of used/waste water purification. Both the number of layering and the order of layering determined the local variation in the degree of attenuation/ motility of bacteria in porous media. It was observed from this paper that layering in descending order of porosity from above is best for reducing microbial load as applicable to slow/rapid sand filtration system (waste water treatment facility). The arrangement in the descending order of porosity gave the higher percentage reduction, hence higher attenuation and retention of bacteria. The larger the difference in porosity (or lower the porosity ratio), the better the stratified layers and the better the filtrate it produces; and the more the number of layering the better the performance of filter bed. There was a kind of fluctuations in the percentage reduction of the two bacteria used in the experiment; this is as a result of their microbiological characteristic. We obtained a 99.48% reduction with D/C/B for Escherichia coli and 97.91% with B/C/D for Staphylococcus aureus. For two layers, we obtained a percentage reduction of 75.43 with descending order (i.e E/A) for Escherichia coli and 77.39 for Staphylococcus aureus.

UNIVERSITY OF IBADAN LIBRARY

REFERENCES

1. **Adegoke J. A, Ogunjobi A. A and Lateef T. A. 2012**. Variation of Attenuation of Bacteria Migration with Volume Flux Rate and Porosity in Porous Media. Global Journal of Science Frontier Research (C) Vol. 12, Issue VI.
2. **Adewumi I., Ojo O. E and Aribisala O. 2004**. Using Filter Sand Abrasion to Predict Flow Rate and Filter Bed Management. Journal of Applied sciences 4(3): 493-497.
3. **Cedergreen H. R. 1976**. Drainage and flow nets. Willey- Interscience Publication, New York.
4. **Dick R. M, Quisumbing A., Behrman J., Biermayr-Jenzano P., Vicki Wilde,** Marco **Noordeloos, Catherine R., Beintema N., 2005**. Engendering Agricultural Research, Development, and Extension. cm.—(IFPRI research monograph). DOI: http://dx.doi.org/10.2499/9780896291904
5. **Fontes D. E., Mill A. L, Hornberger G. M and Herman, J. S. 1991**; Physical and Chemical factors influencing transport of microorganisms through porous media. Appl Environ Microbiol; 57:2473-81.
6. **Jo Sadler and Andrew Goodwin. 2007.** Disease Prevention on Fish Farms. Southern aquaculture center. SRAC Publication No. 4703
7. **Martin, R. E., Bouwer, E. J. and Hanna, L. M. (1992);** Application of clean – bed filtration theory to bacterial deposition in porous media. Environ. Sci. Technol., 26 (5) 1053- 1058.
8. **Olusegun Peter Abiola, 2010**. Lead and coliform contaminants in potable groundwater sources in Ibadan, South-West Nigeria. Journal of Environmental Chemistry and Ecotoxicology, Vol. 2(5), pp.79-83.
9. Smith M. S., Thomas G. W, White R. E and Ritonga D. 1985. Transport of Escherichia coli through intact and disturbed soil columns. Journal of Environmental

Quality. 14:87-91.

10. Raymond Matthew Flynn. 2003. Virus transport and attenuation in perilpine gravel aquifers. PhD thesis, Faculty of Science of University of Neuchatel, Switzerland.
11. Roger C. Bales, Shimin Li, Jim Yeh T. C, Melissa E. Leneczewski and Charles P. Gerba. 1997. Bacteriophage and microsphere transport in porous media: Forced-gradient experiment at Borden, Ontario. Water Resources Research. Vol. 33, No. 4, pg 639-648.
12. United States Environmental Protection Agency, (2000). National primary drinking water regulations: Groundwater rule; proposed rules. 40 CFR Parts 141 and 142. 30194-30274.

© 2013, EJGE

UNIVERSITY OF IBADAN LIBRARY