Effect of Operating Parameters on the Performance of Biosand Filter

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***Abstract*—Thebiosand filter (BSF) is one of the commonly used household water purification methods in the rural areas of developing countries. It is a modification of slow sand filter built on a smaller scale. In the present study, the influence of three parameters, namely charge volume, residence time (pause time between two charges) and influent turbidity on the performance of biosand filter was evaluated. Statistically designed experiments based on the design of experiment (DoE) approach were used for this. Thirteen filtration runs were conducted and the performance of the filter was assessed in terms of turbidity and bacterial removals. Results showed that there was a significant improvement in the microbiological quality of water when the pause time was increased from 12 h to 24 h, although further increase in the pause time from 24 h to 36 h did not result in improvement in the quality. The microbiological quality of water deteriorated with increased charge volume from 10 L to 30 L. The influent turbidity in the range studied (10 - 50 NTU) did not influence the effluent quality. The results of the study thus showed the need for optimising the operating parameters of BSF in order to achieve improved microbial removal.**

Keywords—Biosand filter; colirom removal; household water treatment; turbidity removal

I. INTRODUCTION

Worldwide 1.1 billion people lack access to sufficient quantities of safe drinking water. Unsafe drinking water, combined with insufficient water supply for sanitation and hygiene, is responsible for an estimated 4 billion cases of diarrheal diseases. Access to safer water can in principle be achieved through centralized water treatment and/or point-of-use (POU) treatment. Household water treatment and safe storage (HWTS) interventions have been considered low-cost and effective alternatives for reduction of diarrhoeal diseases that can be implemented at the point of use. In order to address the United Nations Millennium Development Goal (MDG) target no: 7 for water and sanitation, the World Health Organization (WHO) has also identified POU water treatment technologies as an option for providing safe water to households [1]. The biosand filter (BSF) is a commonly used POU system that has been implemented in and over 30 countries worldwide [2].

The biosand filter is a modification of the traditional slow sand filter (SSF) that can be built on a smaller scale. The filter consists of a bed of fine sand supported by a layer of gravel enclosed in a box with appurtenances to deliver and collect the water [3]. A diffuser plate placed above the level of the water protects the sand below from damage when water is poured into the system. As in conventional SSFs, during the ripening process a biolayer (*schmutzdecke)* forms, head loss increases and performance improves. Since the filter is generally charged once daily, generally 20 L, a portion of the charged water remains in the BSF until the next charge. It is reported that approximately 143,000 BSFs were in operation as of June 2007, serving an estimated 858,500 users in 36 countries. Recently, based on performance and sustainability criteria, Sobsey et al.[1] identified BSFs as most effective method among the five different household treatment technologies, and as having the greatest potential to become widely used and sustainable for improving household water quality to reduce waterborne diseases and death. Several studies have been reported on the performance of the BSFs in reducing bacteria, viruses and turbidity from feed water [4, 5,6].

It is known that different parameters influence the performance of BSF. These include sand size, head of water, pause time (that is the time interval between two charges), charge volume and influent turbidity. While some studies concluded that longer pause time and increased residence time each emerged as highly beneficial for improving microbial removal [4,5,7], some other studies [8] showed that increasing detention time did not produce any significant improvement in faecal coliform removal. Recently, Young-Rojanschi&Madramootoo [9] compared intermittent and continuous operation of BSF and showed that continuously operated filters performed significantly better than intermittently operated filters.

In the present study, influence of three parameters, namely charge volume, pause time and influent turbidity on the performance of biosand filter was evaluated. Statistically designed experiments based on the design of experiment (DoE) approach were used for this. Statistically designed experiments are economical, and valid conclusions can be drawn with a small number of experiments. Response surface methodology (RSM) is one such efficient technique for modelling and analysing effects of multiple variables and their responses. It is used for designing experiments, building models, evaluating the effects of several variables and obtaining the optimum conditions for responses with a limited number of planned experiments.Performance of the filter was assessed in terms of turbidity and bacterial removals.

II. MATERIALS AND METHODS

A. Filter Construction and Media Preparation

The filters used in this study were designed based on the guidelines of CAWST [10]. Locally available river sand passing through 1.18 mm and retained on 0.150 mm sieve was used. The sand was washed several times using tap water till the wash water became clean. Plastic containers brought from the local market were used in the study (Figure 1). It was cleaned thoroughly with tap water. Outlet pipe made of PVC was then fitted. Supporting layer composed of gravel (4.75 mm to 12 mm) was loaded into the bottom of the container to a depth of 5 cm and levelled. Next 5 cm separation layer of fine gravel (1.18 mm to 4.75 mm diameter) was loaded above supporting layer. Cleaned filter media was then added to the container to 5 cm below the water outlet level and the media was leveled. Water was present inside the filter before loading to avoid any occurrence of air space and short circuiting. A plastic diffuser plate was then placed on the lip of the filter to avoid disturbance of the top layer during water loading of the filter.

B. Filter Operation

A series of experiments were conducted with biosand filter using selected operating conditions. The operating conditions were selected based on the Box-Behnken design of design of experiments methodology. The three factors included in the study were pause time (12, 24 and 36 h), charge volume (10, 20 and 30 L) and influent turbidity (10, 30 and 50 NTU). The values used in experimental design were decided based on a literature review and preliminary experiments. In Box-Behnken design, all experimental points lie on a sphere of radius √2 (Figure 2) [11].

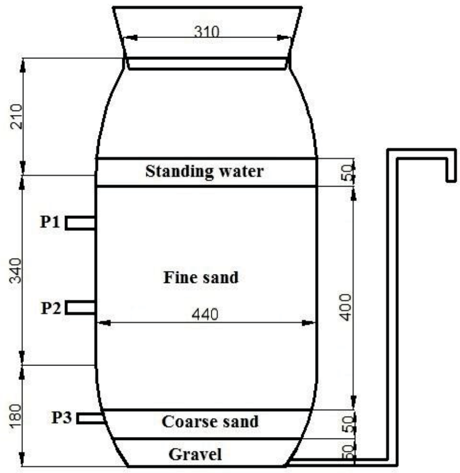

Fig. 1. Schematic diagram of the BSF used in the study. Dimensions are in mm

Table 1 presents the experimental conditions for different experimental runs. In all these experimental runs, tap water spiked with settled sewage at therate of 1 mL/L was used as influent. This was needed in order to get high influent total coliform and faecal coliform concentrations in the range of 10^3-10^4 MPN/100 mL. The required turbidity was added in the form of natural clay. The mean characteristics of the influent during the filter operations were : pH 8.09± 0.2; alkalinity 65 ± 7 mg/L as $CaCO_3$; total hardness 89 ± 6 mg/L as $CaCO_3$;temperature 29.3± 2.3^oC; dissolved oxygen 6.3± 0.7 mg/L; total coliforms $1.32 \times 10^4 \pm 3.1 \times 10^3$;faecal coliforms 1515 ± 441. Influent and effluent samples were collected for each filter run and were analysed for total and faecal coliforms, pH, DO and turbidity. The runs were conducted at room temperature which varied in the range of 27-32^{0}C during the study.

C. Analyses

Water samples for microbial testing were collected in sterilized bottles. Concentrations of total coliforms and faecal coliforms were determined by using the multiple tube technique (most probable number–MPN method). Ten-fold serial dilution was used with 5 tube MPN series. In this experiment, five sets of tubes inoculated with a tenfold difference in inoculums volume between each set was used: one set of five tubes were inoculated with 10 mL per each tube, one set was inoculated with 1 mL per each tube, and the last set was inoculated with 0.1 mL per each tube.Results from only three consecutive dilutions were used to determine the MPN, and the results are expressed as MPN/100 mL.

The mean and standard deviation values of the different effluent parameters were computed, to compare different operating conditions. Also, bi-variable graphical displays were used to analyse the parameters. The analyses were done using Sigmaplot 10 and Microsoft Office Excel 2007.

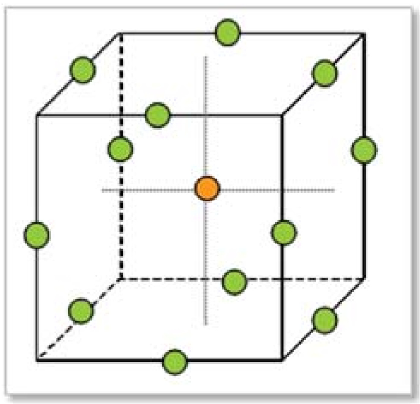

Fig. 2.Box-Behnken design matrix

TABLE I. EXPERIMENTAL CONDITIONS FOR DIFFERENT FILTER RUNS

Run No.	Pause time (h)	Charge volume (L)	Influent turbidity (NTU)
Run 1	12	10	30
Run 2	36	10	30
Run 3	12	30	30
Run 4	36	30	30
Run 5	12	20	10
Run 6	36	20	10
Run 7	12	20	50
Run 8	36	20	50
Run 9	24	10	10
Run 10	24	30	10
Run 11	24	10	50
Run 12	24	30	50
Run 13	24	20	30

III. RESULTS AND DISCUSSION

In order to examine the influence of pause time, daily charge volume and influent turbidity on the performance of biosand filter, thirteen filter runs were conducted using design of experiment approach following Box-Behnken design. Results of these tests are summarized in Table 2. Analysis based on these data are presented in the following sections.

A. Effect of pause time

Figure 3 presents the effect of pause time on various effluent quality parameters. Average effluent turbidity were 1.1, 0.94, 0.87 NTU at 12, 24 and 36 h pause time, respectively. There was a significant improvement in microbiological water quality as the pause time increased from 12 h to 24 h with both TC and FC showing reduced levels in the effluent.However, further improvement was not observed when the pause time increased from 24 h to 36 h. Less frequent inflow (longer pause time) of contaminated source water may reduce the viability of the biofilms removal function relative to more frequent filtration [7].Effluent DO was the lowest at 24 h pause time. From the figure it is evident that pH was least affected by varying pause time.

TABLE II. EXPERIMENTAL CONDITIONS AND EFFLUENT QUALITY FOR DIFFERENT FILTER RUNS

Run No	Pause time (h)	Charge Volume (L)	Influent Turbidity (NTU)	Effluent parameters				
				pH	Turbidity (NTU)	DO (mg/L)	Total coliforms (MPN/100mL)	Faecal coliforms (MPN/100mL)
Run1	12	10	30	7.45	0.89	6.1	33	7
Run 2	36	10	30	7.49	0.87	4.9	7	2
Run 3	12	30	30	7.40	1.07	6.4	110	40
Run 4	36	30	30	7.95	1.30	5.5	70	17
Run 5	12	20	10	7.98	1.23	6.3	110	33
Run 6	36	20	10	7.30	1.12	5.3	40	11
Run 7	12	20	50	7.88	1.27	6.5	70	27
Run 8	36	20	50	7.69	1.11	5.0	33	7
Run 9	24	10	10	7.97	1.03	5.5	22	4
Run 10	24	30	10	7.89	1.03	5.5	60	22
Run 11	24	10	50	7.72	0.78	5.0	26	4
Run 12	24	30	50	7.60	0.83	5.2	70	17
Run 13	24	20	30	7.38	1.01	5.5	33	7

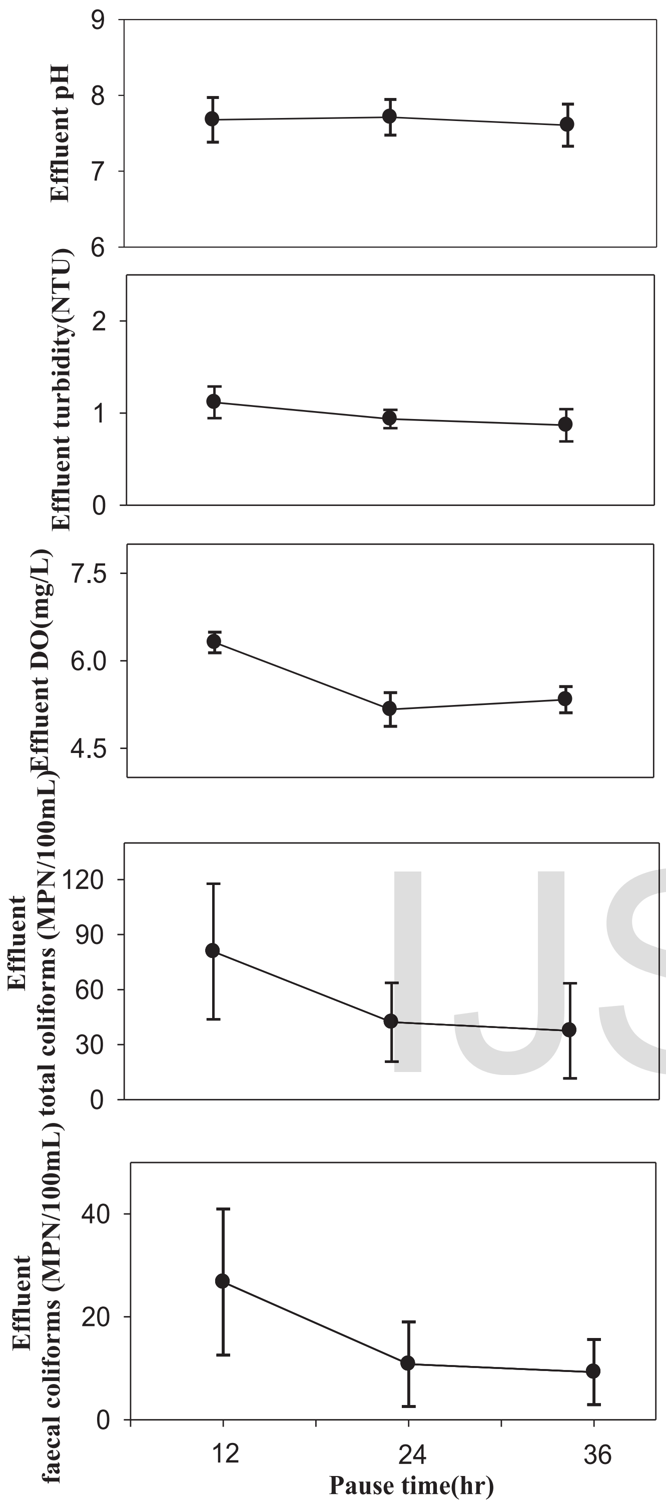

Fig. 3.Effect of pause time on effluent quality

In general, water quality improved with longer pause times compared to shorter pause times. However, the improvement was more significant when pause time was changed from 12 h to 24 h and further increase in pause time to 36 h did not result in significant enhancement of water quality.

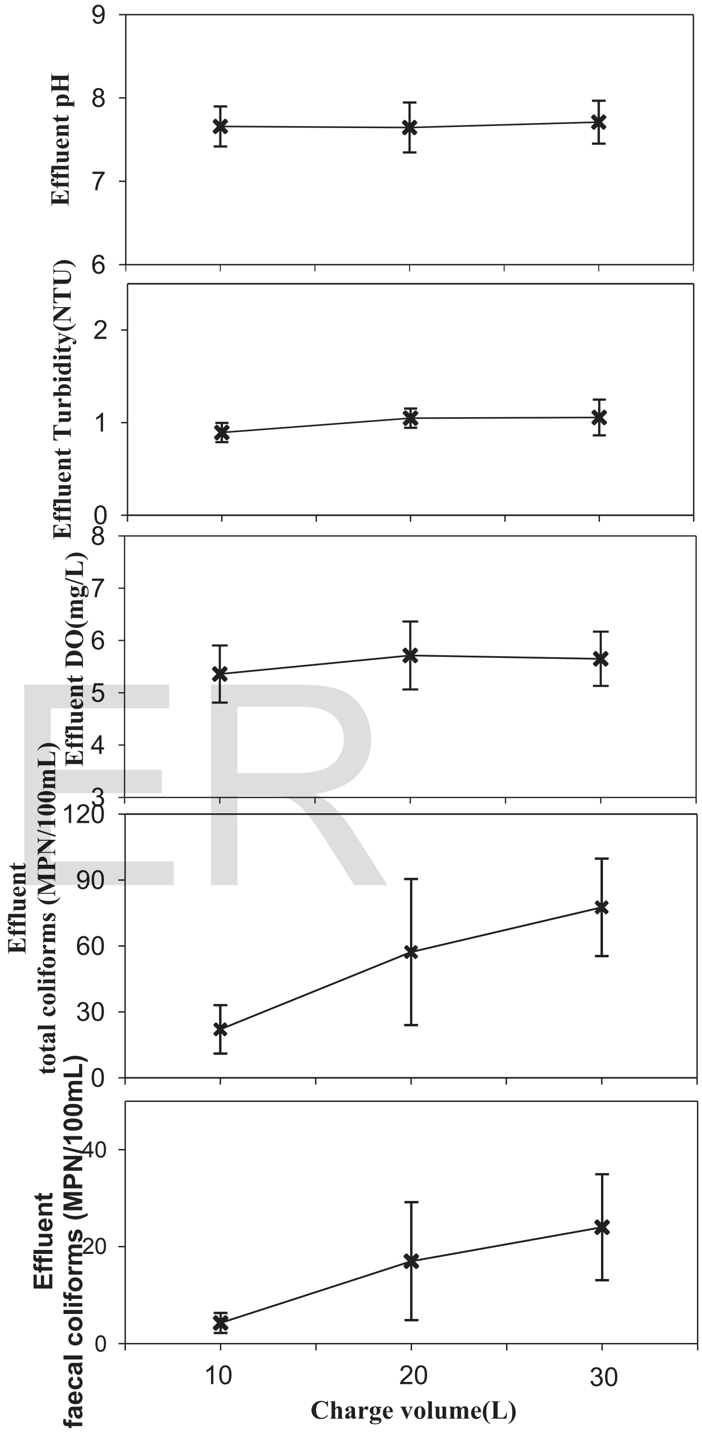

Fig. 4. Effect of charge volume on effluent quality

B. Effect of charge volume

The performance of the filter at varying daily charge volumes of 10 L, 20 L and 30 L is presented in Figure 4. It is evident that effluent pH, turbidity and DO were not affected significantly by the charge volume. Effluent microbiological quality, however, deteriorated as the charge volume increased from 10 L to 30 L. It may be due to the difference in hydraulic loading between the three conditions. When a high charge volume is used, water is pushed through the biofilm and sand at a faster rate, resulting in less exposure to both bacterial predation and adsorption. At lower charge volume sufficient exposure time is obtained, which permits the various bacterial removal mechanisms.

C. Effect of influent turbidity

The effect of influent turbidity on effluent quality is presented in Figure 5 and it shows that no effluent parameters were significantly affected by the increased influent turbidity. Effluent turbidity remained unaffected by the variations in influent turbidity as it increased from 10 NTU to 50 NTU. Jenkins et al. [5] reported positive effect of influent turbidity on bacterial removal. However, in the present study, increased influent turbidity did not improve the bacterial removal.

Several studies have been reported in the literature on the efficiency of BSF in removing various contaminants from water [4,6,8]. Turbidity removal has been reported to be around 85-95% with effluent turbidity values of 1NTU. 80% removal of heterotrophic bacterial populations, 99.9% removal of *Giardia lamblia* cysts, and 50–90% removal of organic and inorganic toxicants have been demonstrated in different laboratory studies [4-8]. The present study also gave similar removals of bacteria and turbidity.

In conclusion it can be said that while microbiological quality is affected by pause time and daily charge volume, aesthetical quality of treated water was unaffected by pause time, daily charge volume and influent turbidity.

IV. CONCLUSIONS

Thirteen filtration runs were conducted with biosand filter in order to assess the influence of three parameters, pause time, charge volume and influent turbidity on its performance. Design of experiments approach with Box-Behnken design was used for this, and the performance of the filter was assessed in terms of turbidity and bacterial removals. Results showed that there was a significant improvement in the microbiological quality of water, when the pause time was increased from 12 h to 24 h, although further improvement in quality was not observed when the pause time was increased from 24 h to 36 h. The microbiological quality of water deteriorated with increasing charge volume from 10 L to 30 L. The influent turbidity in the range studied (10 NTU - 50 NTU) did not influence effluent quality. The results of the study thus indicate scope for changes in the operation parameters of BSFs so as to optimise their performance.

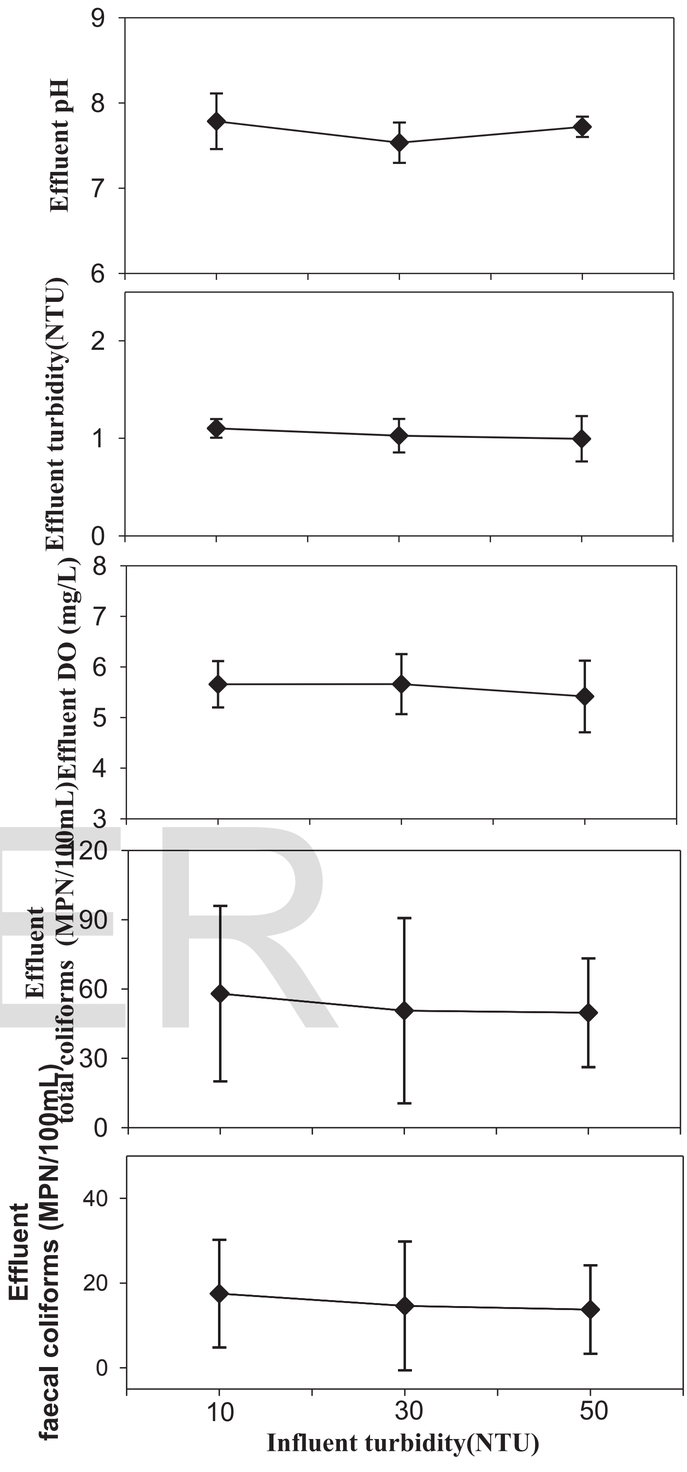

Fig. 5 Effect of influent turbidity on effluent quality

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