Desalination and Water Treatment
www.deswater.com

doi: 10.1080/19443994.2013.879080

54 (2015) 1–7
April

Taylor & Francis
Taylor & Francis Group

Comparison of backwashing with conventional cleaning methods in slow sand filters for small-scale communities

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Received 3 July 2013; Accepted 18 December 2013

ABSTRACT

The application of slow sand filtration technology for domestic water supply was investigated, with particular attention to the issue of periodic maintenance (cleaning the filter layer). The study used raw lake water with a high algal density to allow results to be obtained in a short time. Two filters were constructed with the same filter layer characteristics and were operated in parallel under the same conditions (filtration rate 0.16 m/h and hydraulic load variable maximum 0.80 m). Periodic maintenance was performed when the hydraulic load on the filtration layer reached 0.80 m. One filter was cleaned conventionally and the other by backwash. Nine filtration runs were performed, with an average duration of 14 d. Both filters provided significant improvements in water quality: filtered water turbidity less than 1 NTU, apparent color average of 15 Pt/Co, and removal of total coliforms and *Escherichia coli* around 1.5 log. In general, the quality of filtered water from the two filters was similar. However, the results obtained indicated that the backwash facilitates the operation of slow sand filters by simplicity (opening one valve) and time consumption (7 min), and ensures the water quality in terms of the parameters evaluated, justifying increased use of this technology, especially in small communities and rural areas. Nevertheless, this technology is applicable in small filters (up to 93 m^2), because uniform backwash does not occur in filters with large dimensions.

Keywords: Decentralized water treatment; Slow sand filter; Backwash; Cleaning filter

1. Introduction

At the Fifth World Water Forum in Istanbul, Turkey, it was established that the most important pressure on water supply is the increasing consumption of water due to demographic growth and rising per capita income [1]. The problem is worse in rural areas and urban peripheries. For example, in Brazil, about 33% of rural areas are supplied with water, in contrast to 93% of urban areas [2]. It is therefore necessary to find a cost-effective and sustainable technology to produce water of good quality for domestic and agricultural use, particularly in small and rural communities.

Slow sand filters are considered by many to be an excellent approach to provide a clean drinking water supply in those rural and/or isolated communities

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that have access to a water source that can be treated with this technique [3–5]. These filters operate with filtration rates of 0.1–0.4 m/h, which are factored at 20–50 m/h lower than rapid sand filters [6]. Slow sand filters working at a low filtration rate favors increased biological activity due to the length of time taken for the water to penetrate the medium filter and the absence of pre-chlorination [7]. A major limiting factor of this technique is the quality of the raw water when pretreatment is not used. Cleasby [8] suggests that to obtain good results, the raw water should have turbidity values lower than 5 NTU, non-occurrence of algal blooms (chlorophyll $a < 5\,mg/m^3$), iron < 0.3 mg/L, and manganese < 0.05 mg/L, to reach filtration runs of 1.5–2 months.

Slow sand filtration is easy to implement, involving flow control and monitoring load loss [9]. However, the need for periodic maintenance, namely, cleaning the filter medium, can deter potential users, since this step is very time-consuming if it has to be performed manually: according to Cullen and Letterman [10], five hours are required for the removal of each 100 m^2 surface area of filter. There are various approaches to alleviate this problem, such as harrowing [11,12], the use of synthetic non-woven webs on the sand layer [13–15], the use of equipment that performs the backwash only on the superficial layer [6], and the use of devices with laser-based sensors and vacuum cleaners to remove the superficial layer of sand [16]. The last of these methods does not require drainage of the filter, and a radio-controlled, electrically powered robot can clean the slow filter in the range of 0.5–10 m/min; such equipment has been tested on filters with a surface area of 500–1,000 m^2, reducing the cleaning time from 18–20 to 3.5–5 h [17]. In contrast to these approaches, this paper presents an alternative method of filter cleaning by backwash. Backwashing may provide a method for cleaning SSFs that requires less expensive equipment, less energy intensive, and less labor than the above-mentioned approaches.

Some authors claim that backwash should not be used in slow filters, but did not explain why [18]. According to Hendricks [19], uniform backwash does not occur in filters with large dimensions, which is a possible reason for not using backwash in slow sand filters, since it is necessary to increase the rate of backwash due to the longer side piping, thus increasing the load loss. Hendricks claims that the filter using this method of cleaning should not be larger than 93 m^2 in surface area, but preferably smaller, at approximately 26 m^2. With these dimensions (26 m^2), it is possible to obtain an efficient pumped or high-reservoir slow filtration system with backwash, with a rate of filtration that could supply from 520 to 2,080 people (from 0.1 to 0.4 m/h, respectively), based on the consumption in rural properties of 120 L per person per day [20,21].

Since the filters do not need to be large, the use of slow filtration with backwash could thus be viable in small communities with only a small number of consumers to supply, although to guarantee water quality, efficient operation and maintenance of the system are essential. If backwash is adopted, it is possible to perform periodic cleaning of the filter simply by opening the valves, without the need to remove part of the sand, thereby reducing the time spent in cleaning, and thus the time during which the filter does not produce water, as well as the loss of sand.

This paper describes the cleaning technology and a preliminary evaluation of the performance of backwashed slow sand filters. For this study, two pilot systems were constructed and were operated in parallel for comparison: a slow sand filter with a conventional cleaning method (CSSF) by scraping the initial sand layer and a backwash slow sand filter (BSSF) by inverse flow of its own treated water.

2. Materials and methods

The water used to supply the pilot systems came from a lake (Lagoa do Peri) located in Florianopolis, Brazil. This source has a high density of cyanobacteria (*Cylindrospermopsis raciborskii*), of the order of 10^5 cells/mL, and low turbidity. This raw water would not generally be appropriate for slow filtration, because, according to Cleasby [8], water with a high algal density may compromise the filtration run by blocking the filter with filamentous algal colonies. However, it was chosen for this experiment with the aim of obtaining short filtration runs and thus increasing the number of cleaning operations required.

The slow sand filters were downstream, covered, 0.90 m in diameter, and operated with a constant filtration rate of 0.16 m/h and a variable hydraulic load (maximum 0.80 m), and had a desired production rate of ~2,500 L of filtered water per day, per filter. Flow control at the filter entrance was through a constant head chamber. The filter medium was 0.40 m thick sand layer, with an effective grain diameter of 0.55 mm, and a coefficient of non-uniformity < 1.8, plus a 0.25 m thick support layer, with grains ranging from 1.4 to 4.5 mm in diameter. Larger effective grain diameter promotes greater penetration of impurities, which would prolong the filtration run. Fig. 1(a) shows a schematic of the CSSF design at the time of filtration and Fig. 1(b) shows the direction of water flow during cleaning of the filter medium in the BSSF.

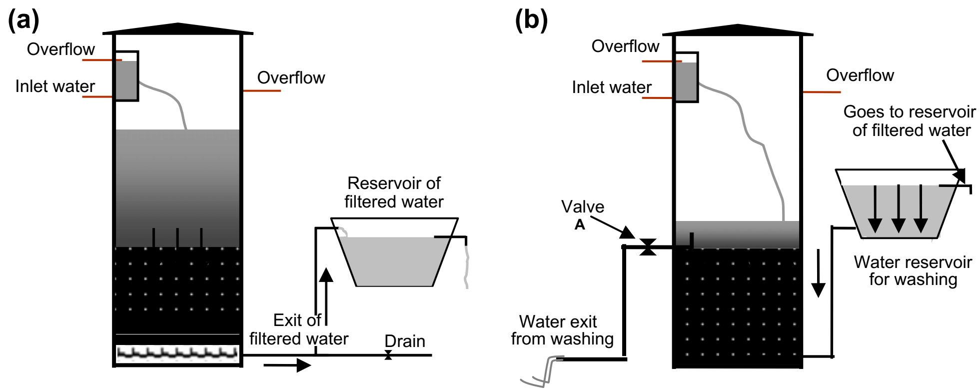

Fig. 1. Slow sand filters: (a) CSSF and (b) BSSF.

When the CSSF reached the maximum stipulated hydraulic load (0.80 m), the supernatant water was siphoned off until the water level was near the sand layer and the drain was then opened until the water level fell to just below the first few centimeters of the filter medium. The biological layer that had formed on the filter was then scraped off, together with ~2–3 cm of sand, and manually washed. Following this, the filter was re-sanded. This operation took approximately 40 min in total.

The BSSF was designed for cleaning by inverse flow and an average expansion of 10%, with the objective of recovering the hydraulic capacity of the filter. From the opening of valve A in Fig. 1(b), the cleaning process took 7 min using water that had already been through the filter and was stored in a reservoir located at a height that allowed inverse flow and provided a hydraulic head sufficient for the expansion of the filter medium.

The filters were compared on the basis of water quality and operational parameters. The following were analyzed in samples of both raw and filtered water: total coliforms (using Colilert reagent), *Escherichia coli* (using Colilert reagent plus ultraviolet light), apparent color (using a Hach DR/2010 spectrophotometer), turbidity (using a Hach 2100P turbidity meter), and algal density (using an inverted microscope with the Utermöhl method). The following operational parameters of the slow filters were also monitored: volumetric flow, hydraulic head (using piezometers), and head loss in the filter layer (using piezometers).

The data were submitted to statistical analysis by Minitab 15. The parameters' color, turbidity, and filtration run time were analyzed by a paired *t*-test. The *t*-test is a hypothesis test for the mean difference between paired observations that are related or dependent. The paired *t*-test is useful for examining differences in measurements before and after in the same element, and differences between the two treatments given to the same elements, which is the case study where the same raw water is subjected to different filters. The confidence level of the test was 95%.

3. Results and discussion

3.1. Quality of filtered water

The parameters evaluated are among those required by Brazilian law (Ministry of Health Decree No. 2914 of 2011); other parameters were monitored in order to evaluate the performance of the filters. Table 1 shows the results for the seven-month monitoring period for each filter system.

The performance of both filters was satisfactory in terms of removal of total coliforms, with average removal rates of 96.8 and 97.2% (1.5 and 1.6 log) for the CSSF and BSSF, respectively. *E. coli* was detected in only one sample from the BSSF, at 3.1 MPN/100 mL; in all the other samples, it was below the detection limit of the method (< 1 MPN/100 mL). These results are similar to those found in the literature, where Murtha and Heller [22] found greater removal of total coliforms and *E. coli* at 30–45 cm depth of the filter media. Brito et al. [23] observed removal by the whole filter layer (75 cm). The removal efficiency of the parameters increases after a ripening period [23]. The removal of total coliforms and *E. coli* in slow sand filters is expected to range from 1 to 3 logs [24–26].

The predominant phytoplankton species in the lake is the cyanobacterium *C. raciborskii*. The CSSF and BSSF exhibited phytoplankton removal rates of approximately 91 and 83%, respectively. The filtration run was long because of the effective size of the sand grains in the filtration media, larger than normally

Table 1
Water quality parameters

Parameter	Raw water[a]	Recommendation for slow sand filtration	CSSF[a]	BSSF[a]	WHO	Brazilian standard
Total coliforms (MPN/100 mL)	2,988 ± 1,014 (1,726–3,970)		95.1 ± 113.9 (8.6–261.3)	83.4 ± 73.7 (3.1–195.0)	Absence in 100 mL[b]	Absence in 100 mL[b]
E. coli (MPN/100 mL)	28.8 ± 18.5 (12.1–51)		<1 (< 1)	<1 (< 1–3.1)	Absence in 100 mL[b]	Absence in 100 mL[b]
Algal density (cells/mL)	$5.5 \times 10^5 \pm 3.4 \times 10^5$ (1.8×10^5–9.3×10^5)	No blooms (Ref. [8])	$4.6 \times 10^4 \pm 1.9 \times 10^4$ (2.8×10^4–6.9×10^4)	$9.5 \times 10^4 \pm 6.2 \times 10^4$ (2.8×10^4–1.7×10^5)		—
Apparent color (Pt/Co)	64 ± 12 (43–114)		15 ± 8 (4–47)	18 ± 9 (6–47)		15[b]
Turbidity (NTU)	4.99 ± 1.31 (3.49–9.98)	< 5 (Ref. [8])	0.93 ± 0.36 (0.47–2.58)	1.07 ± 0.36 (0.54–2.46)	< 5 if possible < 1 (in small systems)	5 (in network)1[c] (treated water)

[a]Average ± standard deviation (data range in parentheses). [b]After disinfection. [c]Slow sand filtration as treatment.

used in slow sand filters, but there was also a breakthrough of algae because the individual *C. raciborskii* organisms are much smaller than the free spaces between grains.

Figs. 2 and 3 show averages of the measurements of apparent color and turbidity during the nine filtration runs. The reference line in Fig. 2 is located in the region of the 15 Pt/Co maximum value allowed by the Brazilian standard for drinking water.

There was a significant removal of apparent color by both filters (76 ± 4 and 73 ± 6% for CSSF and BSSF, respectively), leaving a residual value close to the maximum of 15 Pt/Co allowed. The apparent color is influenced by turbidity, and a high removal of apparent color is taken as a measure of a filter's efficiency in removing turbidity. On the other hand, the true color is related to the levels of dissolved inorganic and organic materials, among them are the humic and fulvic acids from the degradation of organic compounds present in, for example, leaves. An improvement in true color can be obtained, for example, after disinfection with chlorine, which oxidizes organic matter, was not performed in this paper.

The raw water has a low turbidity, mainly arising from the high phytoplankton density. As already noted, this high concentration would count against the application of the technology of slow sand filtration, with regard to the time of the filtration run. According to Ellis and Aydin [27], the greatest removal of solids related to turbidity occurs in the first 400 mm of the filter media, i.e. still in the biological layer, and from this depth onward, only random variations are observed. According to Fig. 3, for both filters, turbidity is reduced to give effluent with an average turbidity of approximately 1 NTU, the maximum value allowed by The Ordinance Brazilian Ministry of Health (MS 2914/2011), which establishes the standards for quality of water intended for human consumption. Removal rates varied during the filtration runs, showing average values of approximately 80%.

3.2. Washing the filter media

During the backwash, the turbidity of the BSSF output was monitored every 30 s in order to determine the cleanliness of the filter medium. It can be seen from Fig. 4 that when backwash occurs, there is an initial rise in turbidity followed by a fall over the course of the wash. The initial increase is a consequence of the expansion of the filter medium during the backwash, by a mean of 10% or 4 cm. This expansion fluidizes the filter layer, causing intense friction between the grains, resulting in detachment of the biological film adherent to the grain surfaces. The detached film then increases the turbidity. However,

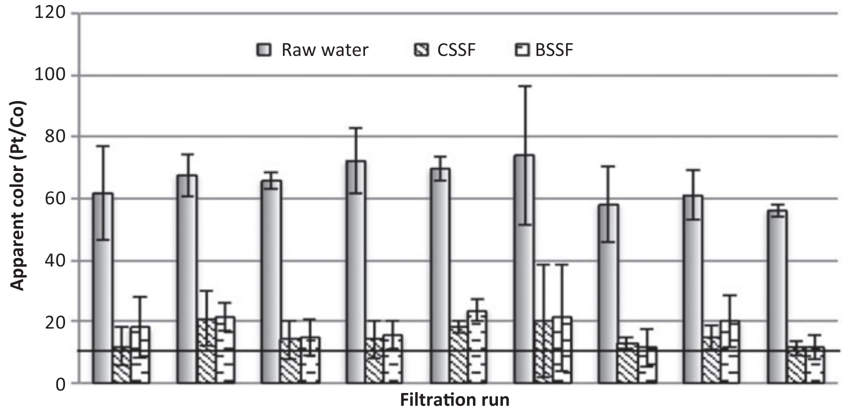

Fig. 2. Effluent apparent color during the filtration runs.

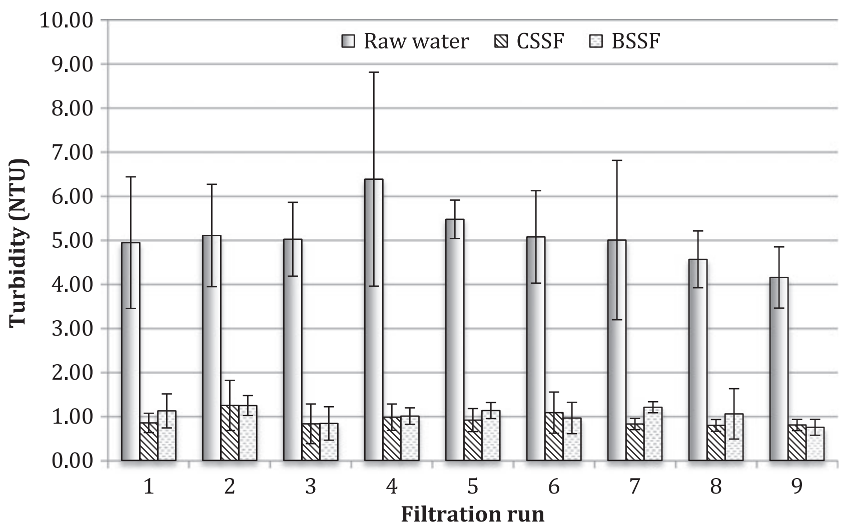

Fig. 3. Effluent turbidity during the filtration runs.

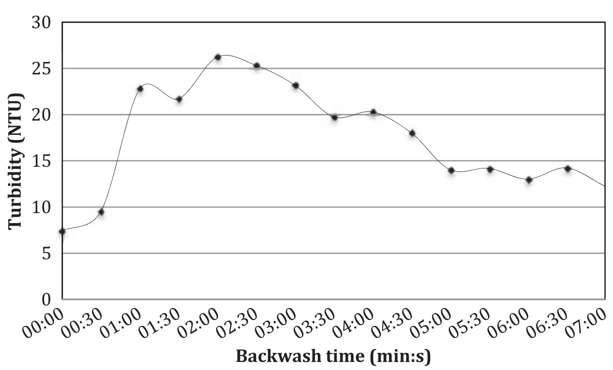

Fig. 4. Average turbidity during backwash.

neither the duration nor the quality of the water from the filtration run is compromised.

3.3. Duration of the filtration run

The slow sand filters studied had filtration runs with an average of 14 d, in contrast to the 30 d to 6 months duration observed by Haarhoff and Cleasby [7] and Cullen and Letterman [10] when monitoring seven New York water treatment stations using slow filtration. The short duration of the runs in the present experiment was a consequence of the high density of algae of the species *C. raciborskii* (see Table 1). This cyanobacterium forms filamentous colonies that speed up the process of filter blockage. Thus, the short duration of the tests was to be expected, despite the small size of the individual organisms allowing greater penetration.

Both the CSSF and BSSF recovered their hydraulic capacity at the end of the cleaning process, a charac-

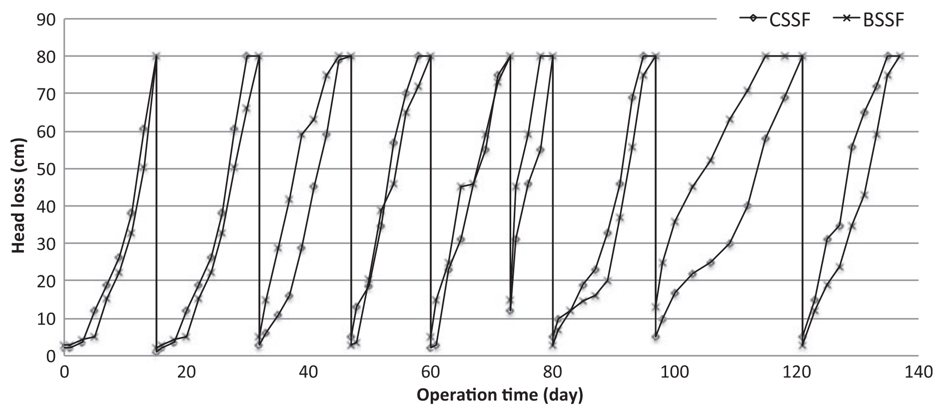

Fig. 5. Development of head loss during the filtration runs.

teristic of proper cleaning, since the loss of the initial load on the filter medium did not increase considerably during the first five filtration runs, as seen in Fig. 5.

The sixth filtration run had a shorter duration than the others, indicating a deficiency in cleaning the fifth filtration run. This can be observed at the beginning of the sixth run, which started with a high head loss of 10 cm, compared with the other filtration runs, which started with a much lower head loss of around 3 cm. However, there was no significant change in the quality of the raw water during the nine runs, and thus it can be concluded that the difference between the sixth run and the others was not due to the quality of the raw water but rather to the insufficient cleaning at the end of the fifth run. The problem was solved in the seventh run, which had durations of 15 and 17 d for the CSSF and BSSF, respectively. On average, the filtration runs ended up with ~75 cm of head loss in the filter medium.

4. Conclusions

This study evaluated the potential use of backwash for periodic maintenance of slow sand filters, targeting their application to water treatment for domestic supplies in rural areas. Filters using conventional (CSSF) and backwash (BSSF) cleaning were tested using the same operational characteristics (rate, hydraulic load, etc.) in order to compare their performance in terms of water quality, initial head loss on the filter medium, and duration of the filtration run. Efficient removal of color, turbidity, and total coliforms was obtained with both filters, indicating that the BSSF does not show any loss in performance compared with the CSSF. The similarity in behavior of the initial head loss in both filters indicates that the backwash was efficient in cleaning the BSSF. The simplicity of this method for periodic maintenance of slow sand filters makes it attractive to potential users of this filtration technology, and a further aid for the provision of a high-quality water supply for the majority of the population.

Acknowledgments

We thank the National Council for Scientific and Technological Development (CNPq) and Support Program for Centers of Excellence (PRONEX) for resources and the Catarinense Water and Sanitation Company (CASN) for providing the physical space for the pilot systems.

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