Bench-scale investigation of Biosand Filter Performance against a Surrogate for Protozoan Parasites

Patty Chuang, Mark Elliott, O.D. Simmons III and Mark D. Sobsey

Department of Environmental Sciences and Engineering, Gillings School of Global Public Health, The University of North Carolina at Chapel Hill

ABSTRACT

Most published research on biosand filter (BSF) performance has focused on reduction of *E. coli* or fecal coliform bacteria with some investigation of virus reductions. Not only have there been limited investigations into the reduction of protozoan parasites, the impacts of filter cleaning on reductions of parasites have never been addressed. Five bench-scale BSF columns were challenged with 2000 per mL carboxylate fluorescent microspheres (d = 4.5 µm, SG= 1.05) as a surrogate for oocysts of *Cryptosporidium* and were charged to five parallel bench-scale BSF columns. Microspheres were captured on membrane filters and examined under fluorescent microscopy to determine concentration. The microspheres are environmentally inert and not subject to inactivation or death, making them an ideal conservative surrogate for protozoan parasites of similar size and density. The goal of this study was to investigate the potential for the BSF to remove environmentally robust protozoan parasites during and after filter ripening and to determine the effect of typical filter cleaning procedures on performance. Overall reductions of microspheres through one-to-two cleaning cycles averaged 99.9% to 99.99% (3-to-4 $\log_{10}$). Following cleaning, significantly higher concentrations of microspheres were found in the filtered water. In conclusion, cleaning procedures that involved disturbing the schmutzdecke resulted in higher concentrations of protozoan parasite surrogates in filtered water, but reductions still exceeded the USEPA standard of 3-$\log_{10}$.

INTRODUCTION

Point of use (POU) drinking water treatment allows those without access to safe water sources to take control of the quality of their drinking water by treating it in their homes. A variety of POU technologies are available, but they vary in microbial reductions and sustained use. Many field studies have been conducted on the implementation and sustainability of the biosand filter (BSF).

The BSF consists of a concrete or plastic chamber filled with sand. An elevated discharge tube allows the filter to maintain a layer of water above the sand surface and prevents dewatering. This allows the sand bed to remain saturated throughout operation, facilitating formation of the *schmutzdecke*, a dense matrix of microorganisms and particles on the surface of the sand media. When organic material passes through the *schmutzdecke*, these microorganisms within the film feed on and degrade the organic material.

The BSF demonstrates potential for large scale adoption, as they are used by at least 500,000 people worldwide. Past assessments of BSF performance have typically focused on reductions of bacteria and viruses. However, there have there been limited investigations into the reduction of protozoan parasites. The ability of traditional slow sand filters to reduce waterborne pathogens is well-documented, but very limited evidence of the BSF's ability to reduce protozoan parasites has appeared in peer-reviewed literature. Moreover, the effect on parasite reductions of cleaning the filter by disturbing the *schmutzdecke* has never been studied.

OBJECTIVES

The objectives of this research were to investigate the potential for the BSF to remove surrogates for protozoan parasites during and after filter ripening and to determine the effect of filter cleaning procedures on performance.

METHODS

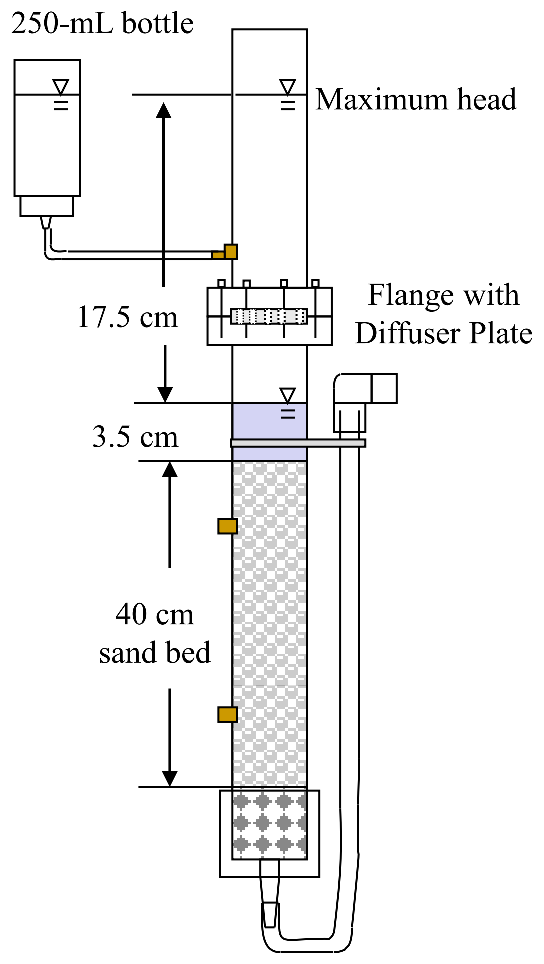

Figure 1: Cross-section of a bench-scale filter column

This study included columns loaded with two types of media: crushed granite gravel and Accusand silica. A charge of 450 mL of local surface water was amended with 2.5% pasteurized primary effluent and spiked with challenge bacteria, viruses, and microspheres. It was poured into each of the six columns to simulate the filtration rate and idle time of the full-scale filter (bacteria and virus data not shown). Carboxylate fluorescent microspheres with 4.5-µm diameter and specific gravity of 1.05 were used as a surrogate for oocysts of *Cryptosporidium*.

Beginning with the initial spike of microspheres, the effluent water from all columns was collected during spike events as well as immediately before, during, and after cleaning the filter. Additionally, various data points were collected during idle times between spike events.

All samples were processed through membrane filters onto 25-mm Nucleopore Membrane Filters (Whatman, Inc.) of maximum 2.0-µm diameter. Following processing, the microspheres were counted using fluorescence microscopy.

To test the null hypothesis that microsphere concentrations before and after filter cleaning have the same continuous distribution, a rank sum test (Mann-Whitney *U* test) was conducted in GraphPad Instat (GraphPad Software, Inc). The use of a rank-sum test was appropriate for this study because there were exactly two unpaired groups of varying sample sizes for comparison.

Table 1: Spiking and Cleaning for Columns

	Granite Column 1 (G1)	Granite column 2 (G2)	Granite column 3 (G3)	Accusand column 2 (A2)[1]	Accusand column 3 (A3)[1]
Initial spiking event	Days 20-22	Days 20-22	Days 20-21	Days 20-22	Days 20-22
First cleaning	Day 36	Day 28	Day 22	Day 36	Day 36
Second spiking event	Days 51-53	Days 51-53	Days 51-53	Days 51-53	Days 51-53
Second cleaning	Day 55	Day 55	Day 55	None	None

[1] Accusand column 1 (A1) data are not included because key samples from column A1 were accidentally discarded during laboratory storage.

RESULTS

Concentration data were collected using the total counted microspheres and volumes of effluent samples. Microsphere concentrations were calculated as (total counted microspheres) / (total volume analyzed).

Influent 4.5-micrometer microsphere concentrations were not significantly different from the target spike concentration of 2000 particles per milliliter. Laboratory analysis of seven samples resulted in a mean concentration of 1664.3 microspheres per milliliter (standard deviation of 595.2).

Table 2: Microsphere reduction after first spiking and cleaning event

	Column G1	Column G2	Column G3	Column A2	Column A3	Mean
Influent microsphere count	2,700,000	2,700,000	1,800,000	2,700,000	2,700,000	
Effluent microsphere count	171.0 13.1	688.0 253.8	2326.5 853.3	1615.8 613.8	1094.8 384.2	
Log_{10} reduction	4.20	3.59	2.89	3.22	3.39	3.46

Table 3: Microsphere reduction after second spiking and cleaning event

	Column G1	Column G2	Column G3	Mean
Influent microsphere count	5,400,000	5,400,000	3,600,000	
Effluent microsphere count	396.0 40.1	1273.16 353.6	3164.3 776.2	
Log_{10} reduction	4.13	3.63	3.06	3.61

The two microsphere spiking events (days 20-22 and 51-53) yielded similar results, with average microsphere reductions of 3-to-4 $\log_{10}$ in the five BSF columns following cleaning. The mean $\log_{10}$ reductions in microspheres for each column are presented in Tables 2 and 3. Only the granite columns (G1-G3) were cleaned a second time because the *schmutzdecke* had not fully developed in the Accusand columns (A2 & A3). It is important to note that, unlike the first spike event, the second spike event was not followed beyond the day after cleaning.

Numerical integration methods were used to calculate recovered microspheres. The effluent microsphere concentrations following the spiking events were used to calculate $\log_{10}$ reductions. These observations indicate that once the BSF is cleaned, the overall concentration of microspheres in the filtered water increases. However, the overall performance still resulted in a mean 99.9% reduction of microspheres (mean 3.46 to 3.61 $\log_{10}$ reduction).

Conducting a rank-sum test on the 29 data points before cleaning and 25 data points after cleaning revealed significantly higher concentrations of microspheres in filtered water following cleaning the five columns (p-value < 0.01).

Overall reductions of 4.5-micrometer microspheres through two cleaning cycles exceeded the US Environmental Protection Agency standard of 3-$\log_{10}$ reduction of protozoan parasites for POU treatment devices.

FUTURE RESEARCH

This study was limited to examining a filter that had been allowed to ripen for 20 days previous to the initial microsphere spike. Moreover, microspheres were only followed for 37 days, whereas BSFs are used for years in the field. Future research should also investigate the BSF performance in filter media that has not undergone any ripening (day 1). Experiments could be extended to a lengthier period of time to simulate BSF field usage. This experiment demonstrates that the *schmutzdecke* is vital in removing surrogates for *Cryptosporidium*. However, it did not study the effect of filtered volumes on sedimentation within the pore space of the sand bed. Further investigations may involve studying the sedimentation and retention of *Cryptosporidium* in the granular media pore spaces during idle time and the impact of decreasing daily filtration volume.

SUMMARY

Investigations of BSF performance have yielded favorable results in sustainability, water quantity produced, and health impacts. However, most published laboratory research on BSF performance has examined removal of bacteria and viruses. Not only had there been limited investigations in BSF performance against protozoan parasites, but the impacts of filter cleaning on performance had never been examined.

A 37-day long bench-scale investigation of BSF performance against fluorescent microspheres revealed that it was successful in removing surrogates for protozoan parasites during and after the filter ripening process. Although filter cleaning caused higher concentrations of microspheres in the filtered water, the mean $\log_{10}$ reduction following cleaning still exceeded the USEPA POU standard of 99.9% reduction of protozoan parasites. Therefore, while filter cleaning is a vulnerability in BSF performance, protozoan parasite surrogate reductions exceeded established standards.

REFERENCES

1. Elliott, M.A., C.E. Stauber, F. Koksal, F.A. DiGiano, M.D. Sobsey. "Reductions of E.coli, echovirus type 12 and bacteriophages in an intermittently operated household-scale slow sand filter." Water Research. 42.10-11 (2008)
2. Palmateer, G., D. Manz and A. Jurkovic. "Toxicant and Parasite Challenge of Manz Intermittent Slow Sand Filter." Environmental Toxicology. 14.2 (1999)
3. Sobsey, M.D., C.E. Stauber, L.M. Casanova, J.M. Brown, and M.A. Elliott. "Point of Use Household Drinking Water Filtration: A Practical, Effective Solution for Providing Sustained Access to Safe Drinking Water in the Developing World." Environmental Science & Technology. 42.12 (2008)
4. Stauber, C.E., M.A. Elliott, F. Koksal, G.M. Ortiz, F.A. DiGiano, and M.D. Sobsey. "Characterisation of the biosand filter for E.coli reductions from household drinking water under controlled laboratory and field conditions." Water Science & Technology. 54.3 (2006)