

Evaluation of Enhanced Pre and Post Treatment Technologies for Biosand Water Filters

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Abstract

There are nearly 1 billion people worldwide that lack access to safe water supplies causing millions of deaths each year, mainly children. Biosand Water Filters (BSF), which are capable of addressing occurrences of microorganisms, are emerging as the preferred technology for household water treatment in the developing world. These systems are simple, inexpensive, and sustainable providing improved microbial reduction for drinking water in rural villages where there is a lack of piped water and electricity. The Biosand filter treats water in a batch process, typically 5 gallons, achieving 95% bacteria reduction, up to 90% virus reduction and greater than 99% cyst reduction. The current work was done to enhance this performance and also address clogging issues encountered on turbid waters in rural settings. A pretreatment coagulation/flocculation step was added prior to the biosand filter and then an automatic post chlorination and safe storage device were also added creating a multistep treatment process. These additional steps were evaluated in villages in Northern Ghana for acceptability and functionality. Users have accepted the pre and post treatment devices and understand the benefits. Preliminary university studies on multiple barrier treatment devices show these added technologies improve overall system performance to > 99.9999 % reduction of bacteria, > 99.99 % reduction for viruses and > 99.9 % reduction for cysts.

Introduction

The latest UN Water Global Annual Assessment on Sanitation and Drinking Water estimates there are nearly 900 million people that are receiving their water from an unimproved drinking water source. Where there is no piped water to homes or villages, there are few choices for people living in such areas to improve the quality of their drinking water and prevent common water borne diseases such as dysentery and cholera. Tragically, this also results in over one million deaths annually, primarily children under the age of five. Geographically, these populations are mainly in developing countries on the African continent.

At the September 2000 meeting of the United Nations, 189 member countries agreed to eight Millennium Development Goals (MDG) which are targeted to be reached by the year 2015. MDG 7c states to "halve, the proportion the population without sustainable access to safe drinking water and basic sanitation". There has been progress toward this goal. It is reported that since 1990, 1.8 billion people have gained access to an improved drinking water source. Fortunately, it appears that this goal will be achieved assuming current gains stay consistent.

For rural communities that have no piped water, water for drinking and cooking is typically collected from a dam (dugout), unprotected surface water source, or a river. When available, the most common technologies to treat drinking water are: 1) Chlorination/safe storage, 2) Coagulation/chlorination, 3) Solar disinfection (SODIS), 4) Biosand filters (BSF), 5) Ceramic clay pots, and 6) Boiling. If none of these treatments are available then water is consumed untreated. If highly turbid, a series of pots to settle suspended solids may be used. Each treatment technology has benefits and limitations based on quantity produced, time to process, treatment performance, affordability, and sustainability. It has been reported that these various technologies differ greatly in how well they address levels of microbiological contaminants (bacteria/viruses/protozoans) that may be in the source waters. Overall, the BSF was scored the highest and shows much promise to help achieving MDG 7c.

The purpose of this study was to design and implement a field evaluation of pre and post filter stages added to the plastic Biosand Filter (BSF). We wanted to know how well these would be accepted, understand water usage, see if users would follow operational guidelines, and see if they perceived benefits from using such devices. Recent lab studies have shown specific microbial reduction performance of these additions.

Design of Pre and Post Treatment Devices

The biosand filter, as designed by Dr. Manz, is an intermittent slow sand filter that uses a bed of sand/gravel and a biological layer to treat pathogens and organic contaminants in water. The version in this study is known by the trade name HydrAid™ produced in the U.S. The BSF treats water in a batch process typically 5 gallons which is poured into the top and collected from the outlet standpipe. Flow is based on gravity, and hydraulic head pressure. The flow rate depends on source water quality, sand, and usage but generally starts at 0.7 liters per minute (lpm) and drops as head pressure decreases, eventually stopping to a static condition. The concept was to design the pre and post treatment devices to mimic what is traditionally done at a modern municipal treatment plant. The pre treatment step chosen was coagulation/flocculation which requires the use of aluminum sulphate (alum).

This step should help address the clogging issues that are typically experienced by BSF users. Depending on source water quality, cleaning of the BSF may have to be performed as frequent as each week. This process disrupts the biological layer potentially decreasing performance. Using a synthetic source water in the laboratory, it was determined that the proper amount of alum to treat 5 gallons was 1700 mg resulting in a concentration of 90 ppm. In the lab this appears to work over a wide range of pH and water temperature. Alum was used in a granular form to ease dissolution. For field use, alum was supplied in individual pre-measured packets.

A custom designed clear plastic coagulation/flocculation funnel was design to nest on top of the HydrAid BSF. This incorporates a valve to release the water once the floc has dropped below a predetermined level. The valve is spring loaded so it will stay in the open position after being pulled and turned 90 degrees. The "clear" water is then dispensed into the diffuser area of the BSF. After the batch is drained, the release valve is returned to its original "closed" position to be ready for a new batch. The floc (or waste) volume chosen was 0.5 liters (approximately 3%). A special scoop is also part of the design that allows for stirring and removal of the floc at the end of a batch, therefore the funnel can stay in place. The floc funnel was also sized so that the original BSF cover would fit on top and still be used to prevent contamination of water being processed.

The post treatment step chosen was chlorination. The challenge was to design a device that could work on the varying flow rate from the biosand filter. A capsule design was created that uses a 1 inch chlorine tablet to contact the water from the biosand filter. The water then flows into a special safe storage container which contains a carbon filter to remove the chlorine when the water is dispensed. The container and filter allow for proper contact with chlorine to provide additional disinfection further improving bacteria and virus reduction. The targeted minimum CT value was 20 to address bacteria and viruses. The size of the storage container was also chosen so that it could be transported when it was moved to dispense. The actual container used is a plastic rectangular 5.3 gallon size with a snap lid. The carbon filter was sized to give maximum flow rate while maintaining the CT target. The filter used is a carbon block with a 4.2" O.D. x 6.5" long that will run at 1.5 lpm when the storage container is full.

The chlorine level therefore is targeted at 3 – 5 ppm to maintain the CT value. The chlorine capsule is also easily accessible so that the tablet can be replaced once it is dissolved from treatment.

The overall system is shown in Figure 1:



Figure 1

It was also desired to collect as much user habit data as possible to understand how much water is used daily by villagers thus determining how long the chlorine tablet would last. Users were instructed to mark the label on top of the storage container after each batch to track water usage. Household information was also collected on number of person living in the home for data comparison. Patents have been filed on these designs.

Field Work

In partnership with Safe Water Team, an NGO with experience in BSF implementation, it was agreed to place 25 sets of accessories into Tamale in the northern region of Ghana. This site was selected due to the known issues of poor water quality (high turbidity) and known use of the plastic biosand filter. In April 2009 twenty-five set of pre and post treatment devices were shipped to Ghana for the trial. In working with local partners at World Vision the units were assembled and placed into 5 villages as listed below:

Pong	8
Pong/Tamale	1
Gbabshie	8
Kpanvo	1
Batangyili	5
Total	23

Users were explained the purpose of the devices, how they worked, and how to use them. They were very receptive and willing to participate in the field trial. A 90 day supply of alum packets was provided to each participant. Supplies of additional alum and chlorine tablets were held by the local test coordinator. Monthly visits were conducted to check on usage and see if any supplies were needed. Photos and data were gathered on usage and questionnaires were conducted periodically.

University Studies

Laboratory testing has been conducted on the pre and post treatment steps to assess how well they perform for microbial reduction. Testing was done on three classes of organisms: bacteria, viruses and protozoan cysts under controlled conditions to simulate field conditions for turbidity and organic load. The organisms tested were: Raoultella terrigena, MS2 and P22 bacteriophages, and C. parvum oocysts.

Results and Discussion

During initial field tests of the floc funnel we used water from the Libga dam near the World Vision Rural Water office in Tamale. The water turbidity did not look very high (< 100 NTU). Other parameters measured; Temp 86 Deg F, pH 7.3, Hardness 1 gpg, iron 0.6 ppm, sulfides and nitrates were below detection. The free chlorine level in the storage container was measured at 37 ppm. The first set placed in the village of Gbabshie had very turbid water, later measured at 1000 NTU. When treated with the alum packet the floc formed in 25 min such that visibly clear water was seen. In this case the floc volume was extremely high and required overnight settling before it could be released into the biosand filter. It was quite significant how quickly the water cleared and local users were surprised.

Generally, the pre and post treatment accessories have performed well in real world conditions in rural households. There were cases of: a) broken release valves which were repaired with replacement parts and b) higher than desired chlorine dosing which was improved with a newer capsule design. The newer capsule design was installed in November 2009. Lab tests show the new chlorine level to be 3 - 4 ppm free chlorine; field data shows a range of 0.2 – 7 ppm free chlorine.

Recent water usage data shows average usage of water is 5.1 gal per day (1.3 batches per day). The average household size is 11 people of which 2 are under age 5. Tablet life studies in the lab using 81 Deg F water show each 1 inch tablet to be capable of treating 600 gallons. Therefore, each tablet should last 118 days or about 4 months.

The 23 biosand units with pre and post treatment accessories have now been in place for over 17 months and all are still in use. A short 5 question survey was conducted in May 2009 and August 2010. Tables 1 and 2 summarize results. A more detailed questionnaire was also conducted to see how well people understood use of the accessories. Questions on health impact were also asked of users. Results are shown below in Table 3.

Additional summarized results from August Questionnaire

- All users are female. 60% are below age 60.
- Nearly 60% stir for 1 - 2 minutes (floc bucket); 25% stir for 3 minutes
- 42% release the water at 30 min while 50% release it after 1 hour
- 42% either throw away the waste (floc) water or give it to animals; remainders use it to wash bowls.
- 100 % of users said they do not move the safe storage container
- 58% of users do not like to see the water level in the storage container
- 50% of floc funnel users and 83% of storage containers want them bigger; while 33% and 8% say it is OK at the current size respectively
- Nearly 60% want the storage container 2X as large; the remainder want it 3X times larger
- 100% have seen an improvement in their health (no guinea worm or diarrhea), skin is fresher
- 2/3 of users admit they marked the usage “almost” every time
- 25% claim to notice discoloration of the floc funnel; no other comments about discoloration
- Discoloration of the Safe Storage container was observed in one or two instances. It was later confirmed that was the effect of chlorine which causes oxidation and precipitation of iron and manganese present in the source water.

University lab studies of pre and post filter accessories showed the microbial efficacy of each stage. Results are shown in Table 4.

Table 1

Accessory Questionnaire Results – Floc Funnel

	May 2009		August 2010	
	(N=)	(%)	(N=)	(%)
Likes about Floc funnel?				
Way it filters/cleans the water before the HydrAid filter	21	91	9	43
It is nice we like it/ everything			5	24
The lid (keeps dirt from entering)	1	4	3	14
Because it is made of rubber			2	10
The color			1	5
Because it uses alum to filter our water			1	5
It is simple in shape and easy to clean	1	4		
Total	23	100	21	100
Dislikes about Floc funnel?				
We like (everything) about it			20	95
Valve is broken			1	5
It is not fast in terms of flowing the water	4	17		
It is small	14	61		
No idea/ nothing I dislike	5	22		
Total	23	100	21	100
What would you improve or change the floc funnel?				
Make it bigger	16	70	17	81
No idea	3	13	2	10
It is OK			1	5
Make it a flexible rubber			1	5
Make hole big to allow water to move fast	4	17		
Total	23		21	100
How would you rate ease of use (1=hard, 5=easy)?				
Easy (rate as 5)	13	57	21	100
Hard (rate as 1)	10	43		
Total	23		21	100
Would you recommend the floc funnel to another HydrAid user? Why/Why not?				
Yes, because...	23	100	21	100
It prevents the dirty water from entering the HydrAid filter	14	61		
it is good and we get clean water from it	5	22	14	67
Because it is very good	3	13		
It gives the water a very good taste than before	1	4		
it prevents water related disease (guinea worm/cholera)			4	19
we are healthy and we want them to be also			3	14

Conclusions

Acceptance of both devices among HydrAid biosand users is extremely high. The surveys show high satisfaction of likes (80 – 91%) with statements such as “We like everything about it”, “The way it cleans the water” The main change requested is to make them bigger. This is interpreted as they want to use more water for their daily tasks of cooking and drinking. This is understandable for the location where access to any water is limited. It also suggests that people are willing to adopt new technologies particularly when it impacts the health of them personally and for their families.

The dramatic visual differences of using the floc funnel to reduce sediment in highly turbid source water has facilitated acceptance. “Seeing is believing” is hard proof that the floc funnel works. (95% - We like everything about it). The ratings on ease of use have shifted from 57% to 100 % over the 15 month period. It suggests that users have gotten used to how it works and believe they are getting real benefits in terms of health impact. The 100% response to their willingness to recommend these devices to other users is tremendous. This was true for both devices at each survey. This also supports their acceptance.

The water usage of 5.1 gal per day is low by U.S. standards but reflect the water scarcity in the northern region of Ghana. It is possible this number is low due to people not marking the container as instructed. Sixty-seven percent

Table 2

Accessory Questionnaire Results – Chlorine/Storage Container with filter

	May 2009		August 2010	
	(N=)	(%)	(N=)	(%)
Likes about Chlorination/Storage Container with filter?				
Everything (about it)			12	57
color/clarity			4	19
It is medicine, and we are aware it is giving us good water			1	5
it gives/ (keeps and stores very) good water	3	13	1	5
it is good			1	5
the size			1	5
don't know much about it			1	5
It keeps water safe from children	1	4		
Well covered and easy to handle	4	18		
It kills germs and prevents dirt from falling in	12	52		
Chlorine inside kills the germs and makes the water very clean	2	9		
It is portable and well covered	1	4		
Total	23	100	21	100
Dislikes about Chlorination/Storage Container with filter?				
We like it			20	95
the valve or releaser			1	5
It is (very) small	7	30		
Smell of chlorine is too much	10	43		
It is small and the smell of chlorine	2	9		
No idea	4	18		
Total	23	100	21	100
What would you improve or change of the Chlorination/Storage Container?				
It is OK (for me/us)			16	76
don't need any changes			1	5
don't know/(no idea)	8	34	1	5
more white			1	5
change the releaser			1	5
better one if there is any			1	5
Eliminate the chlorine odor (remove the chlorine tablet)	4	18		
Make is bigger	11	48		
Total	23	100	21	100
How would you rate ease of use (1=hard, 5=easy)?				
Easy (rate as 5)	18	78	21	100
Hard (rate as 1)	5	22		
Would you recommend this to another HydrAid user? Why/Why not?				
Yes, because....	23	100	21	100
it treats our water and makes it pure	4		8	38
it treats our water for us to drink and we don't fall sick again	5		6	29
it gives us good water and they need some too			5	24
Because it keeps and prevents dirt from falling in the water	9			
It is very good and stores water than before	1			
It makes the HydrAid filter work very well than before	3			
yes (no further comment)	1		2	10

of users agreed they marked the container “Almost every time”. Using the average household size the water per person (0.46 gallons) is close to USEPA estimates of 0.5 gal/person/day for drinking and cooking. The estimated use life of a single chlorine tablet (4 months) seems quite acceptable for increased benefits and low cost.

People generally followed the operational guidelines on stirring and floc wait time. Nearly 60% stir for 1- 2 minutes, half seem to release at 30 min while the remainder wait for 1 hour. The wait time will likely be subjective, source water specific and also subject to seasonal variation.

Table 3

Detailed Use and Understanding Questionnaire Results

	(N=)	(%)
Do you understand the reasons for use of the flocc funnel?		
for filtration	6	50
to prevent disease	3	25
for putting the alum	2	17
to help us have good water	1	8
Total	12	
Do you understand the purpose of the Safe Storage Container?		
for our/my (good) health	9	75
to improve the quality of the water we drink	3	25
Total	12	
Have you had to change the chlorine tablet? How long did it last?		
No	3	25
yes, one month	1	8
yes, two months	3	25
yes, three months	1	8
yes, four months	2	17
don't know/remember	2	17
Total	12	
Do you like that you can see the water level in the Storage Container?		
No	7	58
Yes	4	33
No reply	1	8
Total	12	
Has your health improved since using the BSF accessory?		
Yes, and	12	100
yes, my health has improved /changed to good	5	42
it has improved my life because stomach upset is no more	1	8
yes, no additional comment	6	50
Has your families' health improved since using the BSF devices? Specific comments (a)		
Yes, we are healthy and happy. No guinea worm, no diarrhea	12	100
(a) similar comments by other users		
Have you noticed improvements in your skin, hair, or digestion?		
yes, no reported cases of skin disease in me and my family	4	33
my skin is fresh	4	33
no more stomach pain or diseases	2	17
yes, no additional comment	2	17
Total	12	
Has there been less diarrhea, Estimated decrease?		
yes, > 50%	6	50
yes, 26 - 50%	2	17
yes, < 25%	1	8
no	2	17
yes, no estimated amount	1	8
Total	12	
Other comments on BSF accessories?		
We need to be more informed before you come and we thank you for giving us the filter, we need more	1	8
We will like to thank the mfg. of the device, It has really helped us to have access to good drinking water. It is also a source of medicine to us in this community. We are therefore recommending to people who are in the same situation	1	8
the other houses need some, they always come here to drink	8	67
we are many and we need more filters, we are also happy	1	8
No reply	1	8
Total	12	

Table 4

Lab studies of pre and post filter accessories

	Raoultella terrigena (n=13) CFU/100ml	Coliphage P22 Somatic (n=11) PFU/ml	Coliphage MS2 F-specific (n=12) PFU/ml	Cryptosporidium parvum oocysts (n=4) Oocysts/liter
Mean Influent Seeding Levels	1 x 10 ⁶	4.31 x 10 ⁵	1.16 x 10 ⁵	1.11 x 10 ⁶
Floc Funnel	>99.9999%	97.7%	99.5%	80.1%
Safe Storage Container	>99.9999%	>99.999%	>99.999%	99.9999%
Effluent	>99.9999%	>99.999%	>99.999%	99.9999%

The perceived benefits from the use of these systems are extremely high with all users stating their health has improved. This is evident in the other responses relating to personal health and their families health. "We are healthy and happy. No more guinea worm and diarrhea". It is also significant that half of users claimed that diarrhea has decreased by > 50% since using the devices. Without a true baseline these estimates are hard to validate however users are certainly perceiving health benefits.

University studies on pre and post treatment accessories show what is achievable in terms of microbial reduction. Floc alone is capable of high reduction of bacteria and viruses. Cryptosporidium is lower at 80%. However, when added to the biosand system with post chlorination it brings the overall system up to > 99.999% for all classes of organisms. This is quite impressive for a device that operates without water pressure and electricity.

The pre and post treatment accessories have performed very well in the field trial in Tamale Ghana. After almost 1 ½ years of daily use they are still providing improved microbial reduction for drinking water in rural communities. There have been minor issues with operation but overall the trial has been a great success with users asking for more systems. The health statements are equally impressive and indicate that users understand the benefits from these pre and post biosand treatment technologies.

While the standard biosand filter utilizing sand can reduce microorganisms to a high degree, typically 90 – 99%, the addition of pre and post treatment increases the performance to > 99.999 % further reducing the occurrence of water borne disease in developing countries.

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