Biosand Filtration:
Application in the Developing World

CE 401 Project

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Abstract

The BSF is very similar to the slow sand filters but its use is on a much smaller house hold scale than slow sand filtration. Moreover, biosand filtration is still a relatively new technology that is being applied in the developing world and, consequently, there are continual issues that the BSF must address.

The two main concerns related to the implementation of the BSF are its incapacity to manage high turbidities during monsoon seasons and its high initial cost.

In order to address the BSF's problems with respect to high turbidities clogging the BSF, three pre-treatment alternatives are suggested. The first alternative involves the application of a multistage filtration system. The second method of pre-treatment is using powered Moringa tree seeds as a coagulant. The last pre-treatment alternative reviewed is the use of a sari cloth. The sari cloth filtration is one of the most practical pre-treatment methods because of its simplicity and high particle removal capabilities.

Cost was the second major drawback of the BSF design where the initial cost of a BSF could be a large percentage of a family's annual income in a developing country. Even though the costs of materials range from one developing country to another, the highest costs of the BSF is the concrete container no matter where the BSF is built.

Prior to the implementation of the BSF, studies should be completed on the social, economic, and political factors of the developing country of interest. Only then could the BSF be a potentially sustainable and appropriate technology.

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1.0 Introduction

The demand for water is rapidly increasing at a rate three times faster than the world's population growth. Alarming statistics, such as 1.2 billion people in the world are lacking a safe water supply, have been highlighted at this year's 3rd World Water Forum to confront some of the issues that attribute to the current global water crisis. This Forum and many more in the past and future have consistently emphasized the need for local communities, governments, and non-government organizations to build on sustainable development and technologies to improve water supply and sanitation needs in developing countries.

There are many options in treating our water in North America, however, treatment of water for human consumption in many developing countries is still a widespread problem. A large majority of the water treatment programs in North America are very expensive, complex, and inappropriately designed for the given developing region. The sustainability of any project is reliant on the availability of resources such as power supply, fuel, chemicals, replacement parts, and trained manpower.

Recent studies show that there are 20,000 household size concrete Biosand Filters (BSF) in over 30 developing countries. The BSF is a simple and robust design and is made from readily available materials such as concrete, sand, and piping. However, in the case of almost all projects, the BSF continues to require more research and address issues such as the appropriateness of the design when applied to a developing country, cost, and the technical problems that the BSF encounters under different environments.

This paper will address some of the current issues that the BSF is currently facing after several BSF implementation projects in various developing countries. The main problems that will be looked at are the limited capabilities of the BSF to handle high turbidity levels as well as the high cost of the BSF. An additional topic that is addressed in this paper is the issues that affect the implementation of the BSF in the developing world.

2.0 BSF Background

The Biosand Filter (BSF) is a water filtering technology that was modified from the traditional large-scale community slow sand filter to a small-scale filter for household use. The BSF was developed in 1988 by Dr. David Manz of the University of Calgary, Canada, in response to various issues that were brought to attention from previous water treatment projects. The issues the BSF had to face were higher flow rates than the traditional slow sand filter, effective pathogen removal, improve the taste and appearance of the water, allow for intermittent flow, and still provide an appropriate technology for the developing world.

The function of the BSF begins with the raw water entering into the top of the filter where a diffuser plate is situated above the sand bed and dissipates the water at a regulated flow. The regulated flow is an important factor so as to prevent the disturbance of the biofilm. The water then travels slowly through the sand bed, followed by several layers of gravel, and then collects in a pipe located at the base of the filter. During this time, the water is driven through PVC piping and out of the filter for the user to collect the filtered water.

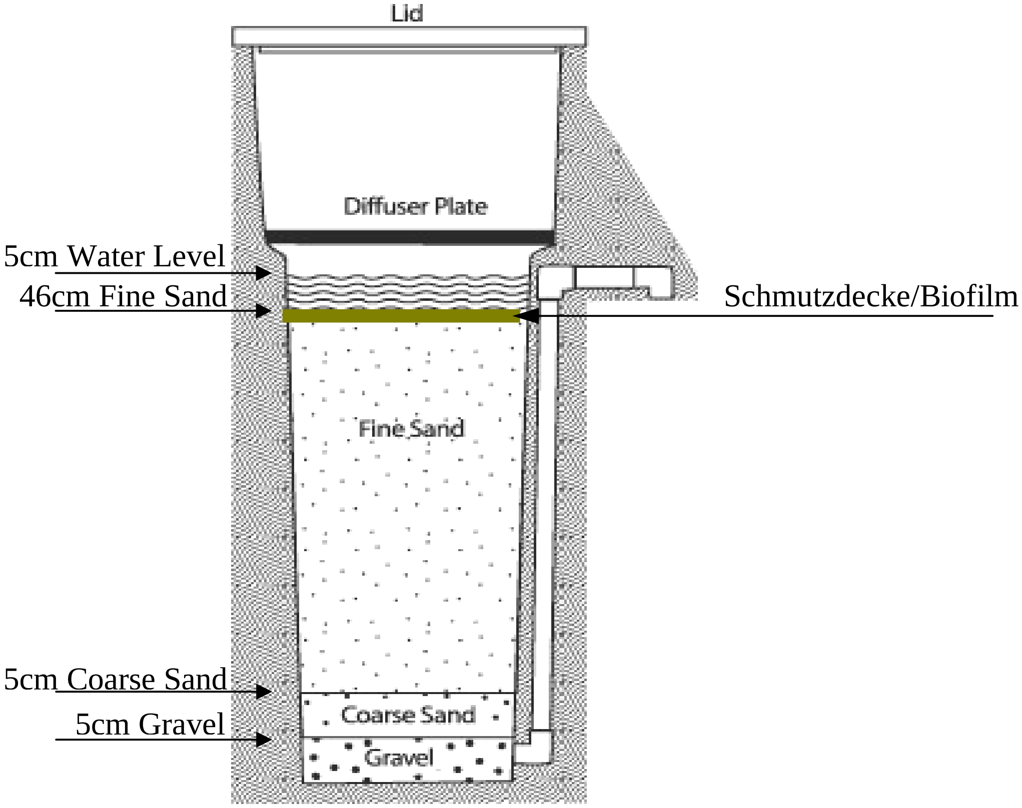

Figure 1: Illustration of a BSF unit

The BSF is similar to the slow sand filter in that the majority of the filtration and turbidity removal occurs at the top layer of the sand bed due to the decreasing pore size caused by the deposition of particles. The BSF removes the pathogens through the same process as in slow sand filtration: as the suspended solids pass through the sand in the filter, they will collide and adsorb onto the sand particles. The processes by which the suspended solids collide and adsorb are straining and adsorption. The bacteria and suspended solids begin to increase in the greatest density at the top layer of the sand, leading to a gradual formation of the biofilm. The biofilm layer is also known as the Schmutzdecke (= dirt blanket) and these two terms will be used interchangeably throughout this report. The Schmutzdecke, which consists of algae, bacteria, and zooplankton, requires the water level to be 5cm above the biofilm in order to survive. As well, the biofilm needs both an aquatic environment and a constant influx of oxygen. Therefore, if the water level above the biofilm rises above 5cm, the oxygen should not diffuse to the Schmutzdecke layer, which would lead to the suffocation of the biofilm. However, if the water falls below 5cm then the inflow of the water through the diffuser will disturb the biofilm. The 5cm water level is quite important to the efficiency of the BSF for the main reasons of preventing the sand from drying on the top layer, and to allow for sufficient oxygen to be maintained for the biolayer by having an outflow pipe in which the pipe stands 5cm above the top of the sand.

The biofilm involves a set of biological mechanisms in which it is not easy to pinpoint a specific mechanism that attributes to the removal, as the system operates in multiple biological and physical mechanisms. The biological mechanisms include:

1. Predation: where micro-organisms within the Schmutzdecke consume bacteria and other pathogens found in the water (i.e. bacteria grazing by protozoa)
2. Scavenging: detritus are scavenged by organisms such as, aquatic worms that are found in the lower layers of the sand beds.
3. Natural death/inactivation: most organisms will die in a relatively hostile environment due to increased competition. For example, it was found that E. Coli numbers decrease as soon as they are introduced into the filter supernatant water.
4. Metabolic breakdown: is a step that accounts for partial reduction of the organic carbon.

The physical mechanisms include:

1. Straining: particle capture mechanism where particles are too large to pass through the media grains.
2. Adsorption: even though a physical process, it still accounts for organic removals that were traditionally attributed to purely biological effects.

It should be noted that there are more biological mechanisms involved in sand filtration, however the five steps mentioned above are the most crucial influences to pathogen removal.

Aforementioned, slow sand filtration is very similar to the mechanics of the BSF. However, there are three definite limitations of slow-sand filter with regards to household level water treatment: 1) it demands continuous flow in order to provide constant influx of oxygen to the biofilm, 2) it is usually built on the scale for community use which requires a centralized water location and is too large for household applications, and 3) requires low level maintenance with regards to the cleaning of the Schmutzdecke layer.

Some of the main benefits of the BSF include:

1) Allows for intermittent flow and can be used only during the times when treatment is required without any decrease in performance.
2) Pre-treatment methods or other treatment process can be used before or after the BSF.
3) BSF has a faster flow rate of 0.6 m/h (30L/hr), whereas the traditional slow sand filtration rates are 0.1m/hr.
4) There is no surface scraping, media disposal or replacement, and very little wastewater. The means of cleaning the Schmutzdecke is through a method called filter harrowing, which will be further discussed later in the paper. The sand within the filter does not need replacement and filter harrowing does not produce a lot of sludge, therefore waste levels are kept at a minimal.

Parameter	Raw Water	Treated Water	Average % reduction
Fecal Coliform (CFU/100ml)	314.0	90.0	71.0
Turbidity(NTU)	35.0	0.7	98.0
Iron (ppm)	3.1	0.0	99.5
PH	6.8	7.2	N/A

Table 1: BSF performance parameters and results

The main components that comprise of the BSF are a rectangular, concrete box, a metal or plastic diffuser plate, PVC piping, and specifically graded layers of sand.

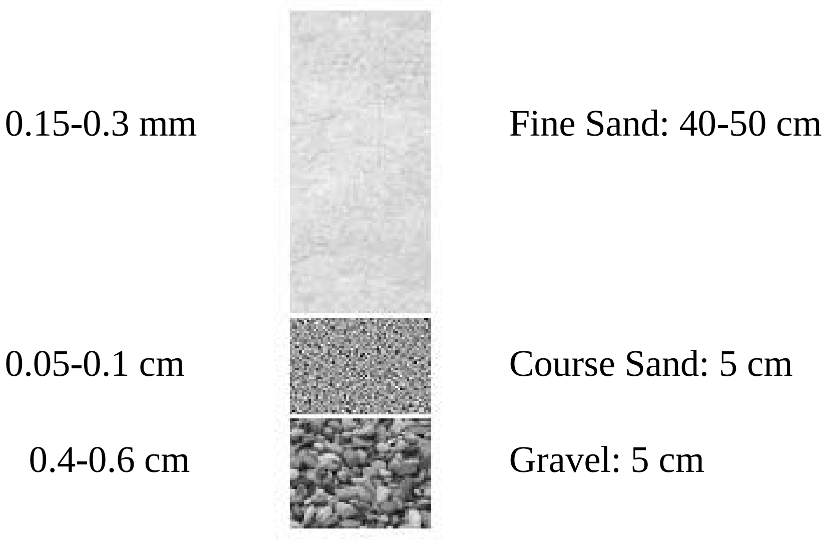

Figure 2: BSF media size (Basu, Cleary, 2003)

Filtration performance in slow sand filters is dependant on the physical characteristics of the filter sand, which include effective size. The effective size, also referred to as the media size, will only allow 10 percent (by weight) of a given water sample to be filtered through slow sand filtration. It should be taken into account that the media size in the BSF will be within the range of the slow sand filter but will not be exactly comparable to traditional slow filters. Most slow sand facilities report to have an effective size that ranges from 0.2 to 0.3mm.

Since the flow rate of the BSF is much faster than the traditional slow sand filters and other filters, like candle filters (0.3 L/hr), I would not recommend that the media size of the sand in the BSF increase more than the current maximum size of 0.3mm. Increased hydraulic loading and increased media size would lead to increased particle breakthrough.

Taking into account that the BSF is versatile, and that biological treatment of the raw water is very successful, there are two major drawbacks of the current BSF technology. These drawbacks include:

1. The BSF's inability to handle high turbidity during monsoon seasons, where the high amount of rain and runoff greatly increase the turbidity. The high turbidity leads to increased particle deposition and decreased pore size. As a result, frequent clogging of mainly the top layer of the sand occurs, reducing the flow rate of the BSF greatly.
2. The cost of the BSF is also relatively high in most developing countries, depending on the availability of the materials.

Through the review of these drawbacks, this paper will derive certain alternatives that can lead to further research within the laboratory and possibly apply to overseas BSF projects. Some of the alternatives that will be reviewed are pre-treatment methods, media size of the sand, and a study done on the cost of the BSF. As well, this paper will address some of the important non-technical aspects of BSF implementation in developing countries, such as, education and community involvement.

2.1 Quantity of Water/Flow

The water flow rate through a slow sand filter is relatively slow and averages about 0.1 to 0.2m/hr downwards. In order for a slow sand filter to perform optimally there should not be any sudden changes in the flow rate and the water should not have increasingly high turbidity levels, otherwise the filter will be clogged very quickly. As the water passes through the BSF, the majority of pathogen removal occurs at the very top layer of the filter bed, where a biofilm layer exists

There are rapid forms of filtration where coarser sand (meaning larger media sizes) would be used, and subsequently the flow is faster where the velocity would range from 4 to 8 m/hr. However, the rapid sand filtration removes a small percentage of pathogens only through low levels of adsorption and straining because the Schmutzdecke layer is not developed in the process. Hence, even though higher flow rates can be obtained from the courser sand media, the water would still have to go through a disinfection filtration stage.

Filter cleaning for the BSF is much simpler than most traditional slow sand filters: the filter does not need to be drained nor is there any raking of the biofilm layer involved. As the filtration rate decreases substantially, the hydraulic retention time will increase, which indicates that the BSF needs to be cleaned. Hence if there is high turbidity and more clogging in the BSF, cleaning of the biofilm is impractically frequent. Although, during normal turbidity conditions the cleaning process involves a smaller form of “filter harrowing” by breaking up the biofilm by gently stirring the water above the biofilm. During the cleaning process, approximately 2cm of the top layer of the Schmutzdecke should be removed. In turn the highly turbid water caused by the stirring will be replaced with cleaner water and adequate flow is then resumed. This maintenance requires no cost and does not have extreme delays in the performance of the BSF. The cleaning operation of the BSF allows the user to use the filter immediately after cleaning because there is no raking involved with the biofilm, thus there is no risk of pathogen breakthrough.

3.0 Pre-treatment

The sand within the BSF requires periodic cleaning because typically the Schmutzdecke layer in the BSF continues to accumulate and grow until the pressure and flow loss due to the top layer becomes excessive. The Schmutzdecke layer in the BSF and slow sand filter are typically cleaned every one to three months depending on the average level of turbidity. However, during regions where there is a monsoon or very wet season, the turbidity is so high that the sand requires cleaning every two weeks or even as frequent as daily cleaning. The amount of cleaning depends on available head, sand particle distribution, the quality of influent, and the temperature of the water. As the filter becomes more clogged and the flow rate decreases, the initial head (5cm above the sand) in the outflow pipe decreases causing the overall headloss to increase. As the media pore size decreases, the amount of particle capture increases. Without cleaning the biofilm particle, build-up of particles will become excessive. An important note is that the majority of the water turbidity could be eliminated in pre-treatment processes preceding the BSF, whereby lowering the amount of suspended solids would reduce the amount of cleaning of the Schmutzdecke layer.

Although there are many forms of pre-treatment methods that are implemented within North America, many considerations and studies must be made on the appropriateness of these methods when implemented in a developing country. The amount and methods of maintenance, availability of materials, level and amount of local training needed to use new technologies, and the cost of these methods are just a few of the variables that will contribute to the success or failure of the project.

Two forms of pre-treatment methods that are considered in this paper are:

1) Roughing filtration
2) Coagulation and flocculation using a powdered form of Moringa Oleifera tree seeds.
3) Sari cloth filter

3.1 Roughing Filters/Multistage Filtration

Roughing filtration is one pre-treatment method that would reduce the particle load and increase the effectiveness of the BSF. In using a downflow roughing filter the water would pass through one or two roughing filters in series. Starting with larger media size in the first filter using course granular media, acting as rapid filters, then the successive filter would have medium to smaller particle size than the initial chambers. This would allow most of the solids to be filtered out with additional removal by the fine granular media. Where each of the roughing filters would progressively remove the large to medium sized suspended solids and the BSF would then filter the smaller bacteria and residual particles. The hydraulic loads and flow rates are often comparably lower than other treatment methods such as flocculation and coagulation. This pre-treatment method would solve the clogging problems in the BSF due to the large media size in the roughing filters. The flow rates for each filter would be different due to the differences in media size. Through past projects, roughing filters are optimal at turbidity removal at turbidities ranging from 200 to 300 NTU where there was a range of 70 to 90% removal efficiency, with a filtration rate of approximately 0.3m/hr.

However this pre-treatment method was deemed not to be a viable solution for the BSF because it does not resolve the high cost issue of the BSF. In fact, it would increase the initial cost substantially due to increased filter materials. As well, the multi-stage roughing filter would add to the complexity of the BSF, which means that more training and education would be involved. In my opinion, this option is not appropriate for household BSF water supply. However if it was applied to a small community water treatment system, the success rate may be higher.

3.2 Coagulation and Flocculation

The removal of a majority of the suspended solids from the raw water would be extremely beneficial before the water enters the BSF, as it would alleviate the majority of clogging problems during high turbidity seasons. For many developing countries coagulation, flocculation, and sedimentation are not feasible alternatives for water treatment because of the high costs involved and the low availability of most chemical coagulants, for example alum. However, there have been recent studies on an indigenous, naturally grown coagulant that originates from a multi-purpose tree called Moringa oleifera Lam. Therefore the use of locally grown and natural coagulant may result in a more sustainable and economically viable alternative.

The seeds of Moringa oleifera have been found to be one of the most successful primary coagulants for water treatment compared to other plant materials that have been tested. This Moringa coagulant is highly recommended for domestic water purification in developing countries, where approximately 3kg of Moringa oleifera has the potential to treat 30,000 litres of water. Moringa has been implemented in various parts of Africa. A challenge with using the powered Moringa as a coagulant is being able to lower the turbidity to standards set by the World Health Organization of 5 nephelometric turbidity units (NTU).

Coagulation and flocculation refers to the process by which particles are destabalised through electrostatic means by the addition of a coagulant, thereby leading to the formation of larger flocs. During coagulation a substance is added to the water to change the behaviour of the suspended solids (SS). As a result, the particles that naturally tend to repel each other will be attracted to each other or towards the added coagulant because the negatively charged particles are neutralized. The process of coagulation requires a rapid mixing/stirring process, followed by the addition of the coagulant. Coagulation is then followed by flocculation, which usually consists of slow stirring. Flocculation is an important step where the coagulant allows for particles to settle at an increased velocity at four times the velocity of unflocculated SS. This additional process to the BSF will lead to a more rapid clarification of the water during high turbidity levels in the raw water. It should be noted that the flocculation stage is quite complex and requires several steps to attain destabilization, which in turn increases the particles removed.

In reference to the Moringa flocculation, a two particle destabilization mechanism which involves charge neutralization and inter-particle bridging occurs. Charge neutralization destabilization can occur by the complexing between an opposite charged protein polypeptide and a suspended particle in the water. For inter-particle bridging, the protein chain concurrently binds to two or more settling particles which forms an inter-particle bridge that can then be separated. (Martin, 2002)

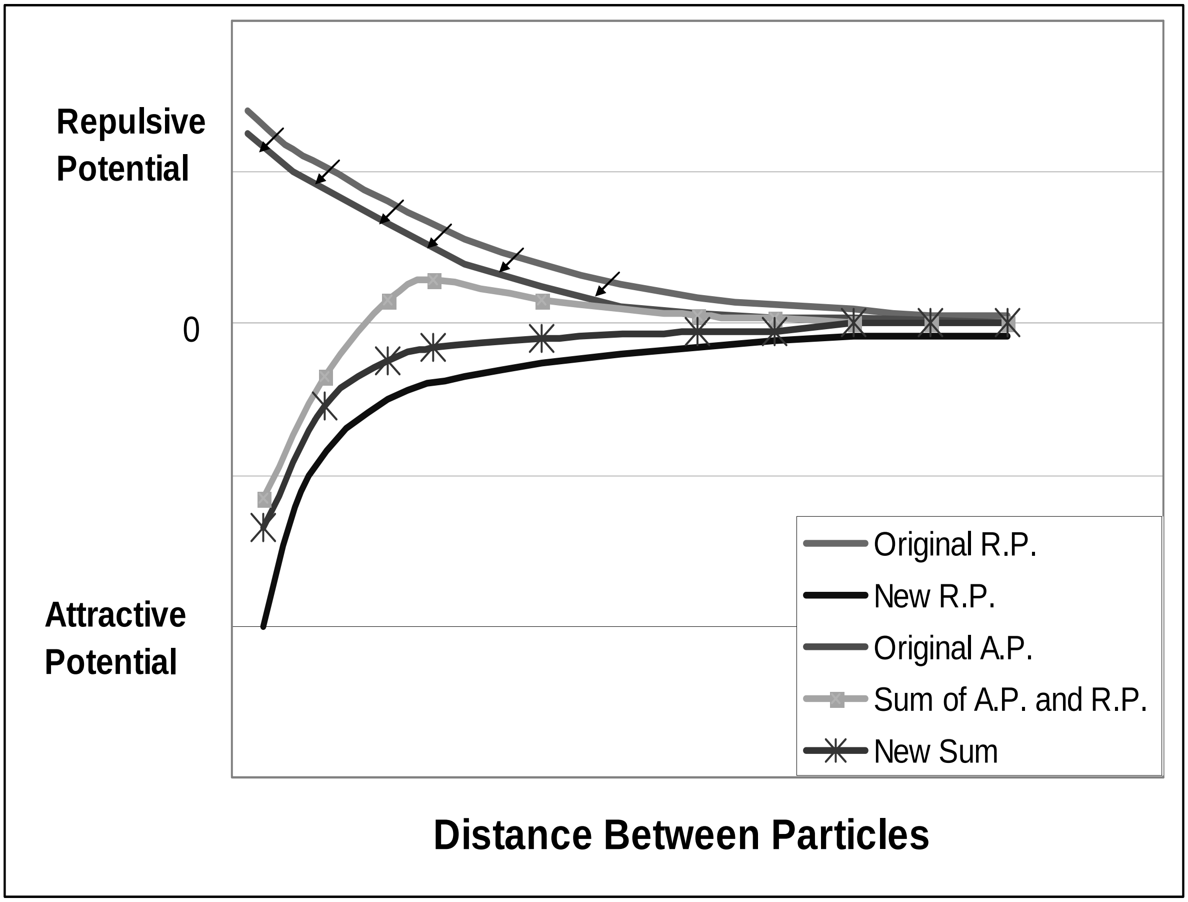

Figure 3: An illustration of the destabilization process

The repulsive potentials are electrical forces and the attractive potentials are gravitational forces. As shown in Figure 3, the original repulsive potential curve reduces in the overall negative surface charge once the coagulant is added to the water treatment process. The arithmetic sum of the original repulsive and attractive potential curves still allows for some repulsive charges. However, once the coagulant is added the new sum of the attractive and repulsive potentials results in an attractive net energy.

The Moringa oleifera plant seed is a process that is based on the flocculation of the SS. Since it is a low cost and portable alternative, this increases its practicality. The Moringa seeds are a cheap flocculant that can be found in many local regions that do not have access to safe drinking water. One of the ways that the village women in Sudan implement Moringa seeds is by placing the powdered seeds in a small cloth bag, and as they collect water from the River Nile, the powder is then swirled around in the raw water. The powdered seed kernels contain considerable amounts of low molecular weight, water-soluble proteins that destabilize particles to agglomerate in order to form larger solid flocs, which lead to quicker sedimentation. The proteins act similarly to positively charged, synthetic coagulants which bind to mostly negatively charged particulates - such as silt, clay, bacteria - that cause raw water to be turbid.

As for the dose of the Moringa used it should be noted that the effectiveness of the coagulant may vary from one raw water sample to another. Although, one benefit of the Moringa powder is that there is a wide range of doses in which the powder still acts as an effective coagulant and can therefore be maintained. Two additional advantages of the Moringa seed coagulant are that its effectiveness has shown to be independent of raw water pH, and it does not affect the pH of the treated water.

A study was done at the University of Waterloo by a group of 4th year environmental chemical engineering students who were doing a study on

Moringa seeds as a coagulant. They used doses of 0, 2, 10 and 25 mL moringa solution for one L of sewage, where, the actual moringa solution was made up of 5 g moringa in 100 mL of water. (Barons, Stevens, Smith, 2003)

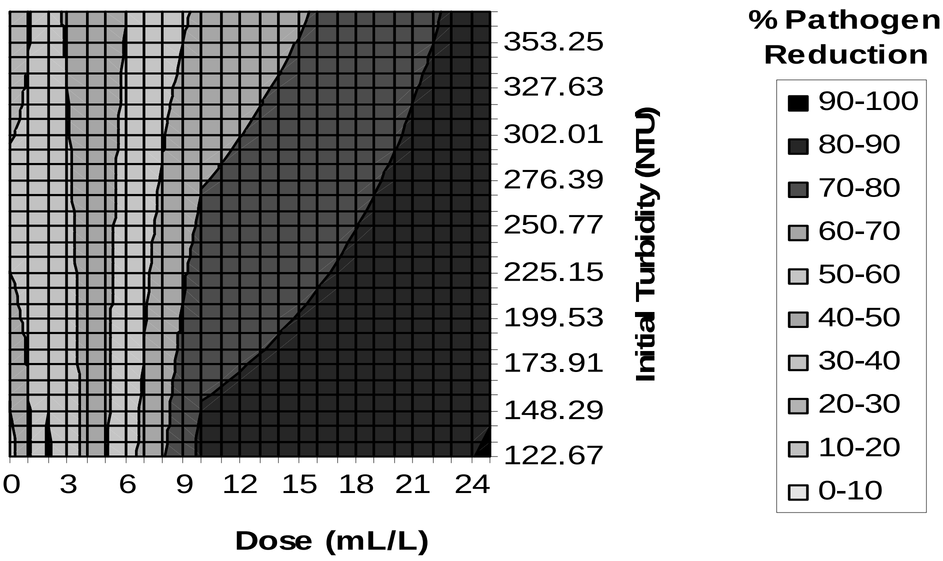

Figure 4: Dose of Moringa solution vs Initial turbidy resulting in varying % Pathogen Removal (Barons, Stevens, Smith, 2003)

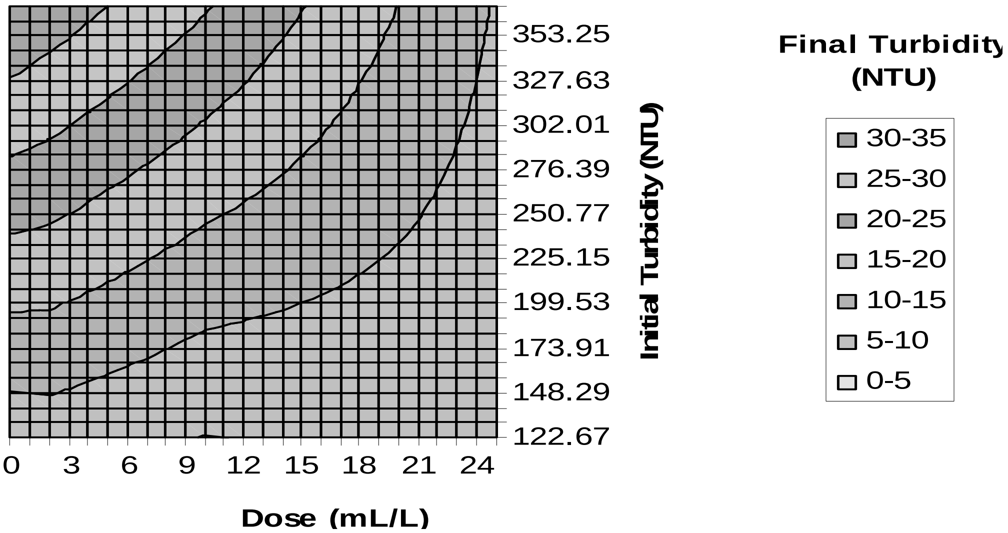

Figure 5: Dose of Moringa solution vs Initial turbidy resulting in varying final turbidities (Barons, Stevens, Smith, 2003)

It is evident in the figures above that as the dosages of the Moringa solution increases the % pathogen removal and also the final turbidity is lowered immensely. As well the WHO standard of 5 NTU was met with initial turbidity ranging from approximately 120-350 NTU; however, any lower turbidities than 5 NTU would not be achieved by the Moringa seed coagulant.

It is important to keep in mind that adding another process prior to the water entering the BSF will lead to an extra step to the educational process and require extra training. Therefore, I recommend that the powered Moringa coagulant only be implemented during the monsoon season rather than different doses of coagulant during dry seasons where the turbidity is low enough for the BSF to be able to handle. The one dose solution ranging from 3-24 ml/L, depending on the level of the turbidity during the monsoon season, will alleviate some of the complexity of the coagulant and BSF training process.

3.3 Sari Cloth Filters:

Rita Colwell, a microbiologist at the University of Maryland, was the primary author of the study based on the correlation between cholera bacteria and sari cloth filters. Since cholera is a waterborne disease, it has become quite prevalent in most developing countries. Many researchers have found that most of the cholera bacteria in rivers, ponds, and other forms of standing water would attach themselves to or in the gut of a copepod, a type of zooplankton commonly found in standing water. Through human consumption of this unfiltered water, people consume these copepods which leads to the cholera bacteria entering into their system.

It has been common practice for villages in Bangladesh to use a folded piece of sari cloth to filter their drinking water. In laboratory experiments, it has been found that sari cloth that is folded four to eight times provides a filter of approximately 20µm mesh size. Therefore, the sari cloth can filter out all zooplankton, most phytoplankton, V. cholerae attached to plankton, and particulates that are greater than 20µm. Studies showed that the sari cloth, folded four times, was able to remove 99 percent of the V. cholerae cells that were attached to the plankton. Nylon mesh that was also used in the studies with a pore size of approximately 150µm also had successful results in removing the cholera and other bacteria. The filters are wrapped over the neck of the water container and when the container is dipped into a pond or river, the water can only enter by passing through the sari or nylon cloth.

Experiments have shown that as the sari cloth is repeatedly washed, the pore size between the cloth mesh decreases and therefore traps finer particles. (Colwell, 2002)

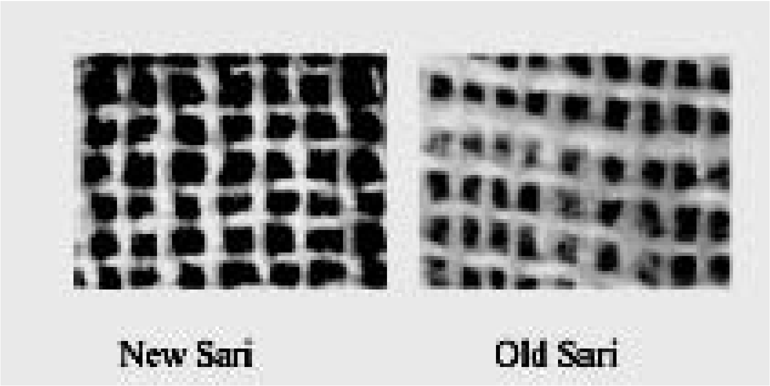

Figure 6: Comparison of pore size between New and Old Sari Cloth (Colwell, 2002)

Emphasis should be put on the importance of educating the local people using the cloth filter to decontaminate the cloth filter after each use. Whereby, the user, after filtering, would removed the concentrated plankton by rinsing the cloth filter in the same river or pond water, and then a second rinse with the previously filtered water, followed by air drying in the sunlight. It should be noted that the water containers must be cleaned out daily in order to prevent growth of biofilm.

Both the nylon and sari material were effective in filtering out the copepods and other SS, but the sari cloth is much less expensive in some regions. However, it is safe to assume that other materials may have similar effects as the sari cloth, keeping in mind that the cloth filtration is a pre-treatment method for this paper. Since most colloidal turbidity particles range from 0.5 to

100µm, the sari or other cloth-type filters would effectively remove large particles, leaving particles that are smaller than 20µm to be captured in the BSF. As well, in order to incorporate the sari cloth with the BSF the cloth would be wrapped over the top of the BSF, still allowing for oxygen to diffuse through.

4.0 Cost of BSF

Since the cost of the BSF can be one of the drawbacks for extensive implementation in the developing world, it is definitely a concern that must be addressed. In Nepal the cost of the BSF is approximately Rps 2,500 (CDN$48), which is about 15% of an average Nepali family's annual income (CDN$330). Realistically, most families would only be willing to spend up to 5% of their salary on the BSF. Although the price range of the BSF varies depending on the local prices of the materials where the BSF is built, the cost range is still on average CDN$30-40 around the world. Even though the BSF is a one-time cost and the maintenance is free, it is still very challenging and unlikely for a family to make such a considerable investment. The cost breakdown given by Centre for Affordable Water and Sanitation Technology (CAWST) is shown in Table 3 is a cost analysis done by a group of students trying to implement the BSF in Guatemala.

Materials	Cost ($CDN)
1 Bag Cement	6.21
Sand & Gravel	2.88
Wood	3.67
PVC elbows	1.04
PVC pipe	0.39
Metal diffuser	0.39
Vegetable Oil	1.97
Total	16.55

Table 2: BSF material cost breakdown

Given that cement is notably the largest cost, the price of a plastic filter was researched at Davnor Water Treating Systems in Canada. The equivalent model to the concrete biosand filter has a retail price of CDN$235, keeping in mind that the cost would reduce if 1000 filters were bought. Studies have also been done on cutting back the amount of cement used in the concrete but this resulted in a much lower quality filter that led to cracking and leaking. Hence it is not advisable to reduce the cement, sand, gravel ratio to anything less than 1:1:1, respectively. Alternative materials for the BSF container definitely have to be researched in the near future. The greatest challenge is that the container has to be water tight, durable, easily obtained, and low in cost (i.e. old garbage cans, brick, and mortar).

The next piece of material that was studied was the cost of the diffuser plate where in some countries wood is used; alternatives are steel, plastic, or concrete plates. In Haiti, the Dominican Republic, the Amazon, and Nepal they use a plastic or steel diffuser that is relatively inexpensive. The use of concrete diffusers is cautioned against because they can be quite challenging to produce and can crack easily. Since the diffuser plate is an essential element to the BSF, it is best not to reduce costs on this item. It should be noted that the cost of the wood in the cost breakdown could be eliminated if the diffuser was not made of wood, otherwise the metal diffuser would be eliminated.

The cost of each steel mould for the concrete BSF container can range from CDN$400 (produced in Haiti) up to CDN$2200 (produced in Canada), again depending on the region the cost of the mould will vary. It is estimated that each mold could create 1500 filters over 5 years. Hence, even if the filter cost CDN$2200, the capital portion chargeable to each filter would be CDN$1.46 per filter.

An important point to highlight when considering the average cost of the BSF is that the cost will vary depending on the region the BSF project is located. For example, the BSF costs CDN$48 in Nepal and CDN$12 in Vietnam. One way of alleviating a portion of the BSF cost is allowing the villagers to assist in part of the project such as drying, sieving, and washing of the sand, and lid building. An example of this option being successful is in Cambodia where the families contribute one day's labor and CDN$1.50 contributes to pay for their BSF. (Lukacs, 2002)

Currently, a Massachusetts Institute of Technology (MIT) student is researching alternative BSF materials in Nepal. The alternatives considered are fibreglass and plastic BSFs. Through preliminary discussions at MIT the total cost of the fibreglass BSF would range from CDN$23 – CDN$29. I would strongly recommend that further research be done on several different options for materials that could replace the concrete BSF container.

Consequently, it is evident that prior to implementing a new technology in the developing world, it is crucial that the unit cost should be broken down into each part comprising the BSF, transportation, manufacturing, and educational costs. As well, an analysis should be done on not only money costs, but should also adjusted to reflect real opportunity costs, such as health benefits minimizing costs in the long run. Economic sustainability of a project has to include the measure of risks and benefits of alternative technologies that involve supplies that need replenishing and/or additional maintenance costs. Even though the BSF does not have operation and maintenance costs, the risks and average filter lifetime need to be evaluated with the high initial costs. (Lukacs, 2002)

5.0 Implementation of BSF

In many developing countries adequate sanitation facilities are scarce to nonexistent especially in the rural areas. Sanitation issues increase when areas, rural or urban, become densely populated without appropriate water treatment services and sewage is left untreated in the community's drinking water supply.

Prior to implementation of the BSF, studies should be performed to evaluate whether or not the BSF would be an acceptable technology based on customs, traditions, and cultural values. In turn, the acceptability of the BSF technology will drive the level of demand and determine the sustainability of this technology within the existing social structure.

The assessment of local demand should be the main concerns of project before the introduction of new technology. In most scenarios, people will choose the most socially, culturally and economically acceptable water treatment option. (Lukacs, 2002)

5.1 Community Involvement and Education

Community involvement is a concept that is still not clearly defined with regards to water supply and sanitation projects in developing communities. There are many concepts that are attached to development work, such as appropriate technology, community participation, and sustainable development. Hence, caution must be taken so that these words do not just become fashionable terms that should be obviously defined and applied to each project. The reason being is that each development project is unique in region, resources, technology, skills, and challenges.

Many answers are essential to questions such as:

1. Who within the community participates? When? And to what level?
2. To what capacity do community members participate?
3. How does a project encourage community involvement to thrive and be maintained?

(IRC, 1984)

There are many variables that influence the level of participation within a community which may depend on political factors, types of technology used, scale of projects, socio-economic and cultural differences that demand a certain level of flexibility and contingency plan. In forming a strategy to put into practice for sanitation and hygiene education and community involvement, flexibility is crucial in order for local adaptation.

Community participation and the health impact of the new water supply can be increased by integrating an education program as part of the project. Hygiene education is crucial to be planned with the community in order to bring awareness to the public of the direct relationship between disease, water, and sanitation. Only then will people be more conscious of their own behaviour and facilities. For example, people must first understand that not only does filtered water taste and smell better, but it has a direct correlation to filtering many of the waterborne diseases. In addition, hygiene education can prevent users to use contaminated water containers for filtered water and/or to prevent contamination of the BSF water tap which will subsequently contaminate the whole water supply coming from the BSF.

One of the major criterions that determine the sustainability of a project overseas is that the technology can be created and maintained locally. From the experience of past development projects, the most successful projects are the ones that do not necessitate outside assistance, hence materials must be locally available. In order for the technology to be maintained locally, each project should build in an education and training cost so that the technical aspects of the BSF are well understood by some trained technicians.

A major challenge that the BSF must confront is educating the users on the significance of the biofilm and proper filter maintenance techniques. The Schmutzdecke layer is fundamental to effective removal of viruses, bacteria, and turbidity. For that reason, the uniform growth of the biofilm is crucial to the operative success of the BSF and raises the importance and need of education.

5.2 Case Study – Inappropriate BSF application in Nicaragua

An MIT student, Bruno Miller, did a study on the reasons that lead to the failure of the BSF distribution project in Nicaragua. In addition to being a war torn country, Nicaragua was struck by hurricane in 1998 where an estimated damage to water and wastewater systems was approximately over US$560 million, affecting an average of 800,000 people. In consequence to this natural disaster, thousands of BSFs were distributed throughout the country in hopes of resolving some of the polluted drinking water issues and improve the living conditions of the population (Bruno Miller, 2002). However, this specific BSF project did not conclude with the positive results and definitely not as successful as the project had planned to be.

Through Miller's investigation a number of problems arose in the inappropriateness of the design as well as the operation and maintenance aspects of the BSF. With regards to the design issues, the filter could not be produced locally in rural locations due to the lack resources to produce the materials (i.e. PVC piping, cement). As well, the BSF arrived as 'filter kits' which involved many parts that made wide distribution very complicated, especially in such a desperate situation as the one in Nicaragua. Furthermore, the BSF is not easy to maintain and operate without proper training, hence, it may have been the wrong water treatment option to send for quick relief aid. Due to the lack of education, people were using contaminated containers to capture the water. As a result of lack of resources, proper monitoring of the BSFs was not provided. This is an example of a situation where the BSF may not be an appropriate technology for emergency short-term water treatment following natural disasters.

6.0 Conclusions and Recommendations

The BSF has many similarities to the traditional slow sand filters but its use is on a much smaller scale than slow sand filtration. Furthermore, biosand filtration is still a relatively new technology that is being applied in the developing world and, consequently, there are continual issues that the BSF must address.

The two main concerns related to the implementation of the BSF are its incapacity to manage high turbidities during monsoon seasons and its high initial cost.

In order to address the BSF's problems with respect to high turbidities clogging the BSF, three pre-treatment alternatives are suggested. The first alternative involves the application of roughing filters, where one or two rapid filters in series would be followed by the BSF. This method resolves the high turbidity problems; however, it is not recommended due to its high increase to the initial costs of the BSF.

The second method of pre-treatment is using powered Moringa tree seeds as a coagulant. Results from past studies showed that the Moringa solution can lower the turbidity levels to 5 NTU with doses of 3-24 ml/L. In order to simplify the operation of the BSF, it is recommended that the Moringa seed coagulant only be applied during monsoon season. Whereby, only one dose of coagulant would be applied during the times the water was very turbid. Due to the low cost and efficiency of the powered Moringa coagulant, it is highly recommended that it should be used as a pre-treatment method in regions where Moringa trees are readily available. It should be noted that past studies have not shown that Moringa seeds have any adverse affects on the biofilm, however, this concern should be researched further.

The last pre-treatment alternative reviewed is the use of a sari cloth. This method is the cheapest, least labour intensive, and requires little training because many local people use this method already in areas such as India. The pore size of the sari filter can be as small as 20μm, which captures many of the SS and bacteria. It is assumed that many other materials would have similar results to the sari cloth, however, it is recommended that further research should be performed regarding this matter. Additionally, an investigation into the possibility of replacing the BSF diffuser with the sari cloth is recommended. The sari cloth filtration is one of the most practical pre-treatment methods because of its simplicity and high particle removal capabilities.

Cost was the second major drawback of the BSF design where in Nepal the initial cost of a BSF could be as high as 15% of an average family’s annual income. Even though the costs of materials range from one developing country to another, the highest costs of the BSF is the concrete container no matter where the BSF is built. Currently, CAWST and students from MIT are researching alternative methods to lowering the cost of the BSF by investigating different materials such as fibreglass and plastic.

Prior to the implementation of the BSF, studies should be completed on the social, economic, and political factors of the developing country of interest. Along with studies on the socio-economic situation, education is crucial to the success of the BSF being properly operated by the local people. Only then could the BSF be a potentially sustainable and appropriate technology. It is essential for the implementation of large scale BSF project (i.e. over 100 BSF being implemented in a developing country) to form a highly interdisciplinary team in order to tackle the social, economical, health, and educational facets that the project will face.

With the proper studies and a suitable and well balanced team cases like the Nicaragua BSF project could be prevented.

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