

# **BioSand Water Filter Technology**

## **Household Concrete Design**

**By**

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**January 22, 2021 update on statistics (Originally published April 30, 2007)**

### **Acknowledgements**

The concrete household BSF technology was developed with the support of my wife, numerous students and staff in the Department of Civil Engineering at the University of Calgary, Dr. Mel Kerr of the Division of International Development also at the University of Calgary, Samaritan's Purse Canada, Rotary International (particularly Calgary South), Ranger Oil, and numerous other individuals in government and non-government organizations in Canada, Nicaragua, Honduras, Chile and Indonesia. Particular credit must be given to Davnor Water Treatment Technologies Ltd. and its staff.

The BSF technology has been patented in Canada, the United States and several other countries to insure commercial (rapid) development of the technology outside of the University community. The development of the BSF technology for humanitarian purposes was greatly accelerated by opportunities for its commercialization. The BSF technology is not limited to household concrete filters. A wide variety of plastic, stainless steel, and concrete BSF's ranging in capacity from 20 to 240,000 liters per hour are available under license from the Canadian company, Pure Filtered Water Ltd., Calgary, Alberta, Canada. Only the household concrete BSF is available without royalty of any kind to everyone worldwide, without limitation, provided they are appropriately trained and faithfully represent the BSF technology.

### **Introduction**

The BioSand Water Filter or BSF as it has come to be known was developed in response to the need to provide adequate quantities of aesthetically pleasing, 'safe' water to disadvantaged people, households and communities worldwide. Since the time the first filters were constructed in 1990 many

thousands of household concrete BSF's have been built and operated. The BSF technology has been subject to continuous performance and consumer evaluation. In every study BSF's have been proven to be an effective, affordable, robust, appropriate, accepted and sustainable water treatment technology. The BSF technology has lived up to the expectations and is fulfilling the role envisioned. Most important the BSF technology has been proven to greatly improve the health of its users. According to recent estimates (2020) there are over 2,000,000 BSFs installed in most developing countries worldwide. A Google search using 'BioSand Water Filter' will yield over 800,000 sites (1,500 sites in 2007). The use of the BSF technology is growing rapidly.

The household concrete BSF technology has been made available to all those who wish to take the appropriate training. In so doing they assume the responsibility for implementing the technology as instructed and to pass on their knowledge with integrity.

There is considerable published knowledge on water treatment; slow sand filtration in particular, authored by many scientists, engineers and health workers. All information that could be found was considered in the development of the BSF technology. The quality of water that a treatment system must produce to be safely consumed by humans is well established. Water treatment plant design, construction, operation and maintenance are also well understood and are constantly being advanced. New information is always being written and published and when discovered is carefully reviewed in the hope that additional insights would be found that might provide opportunities to improve the BSF technology.

Scientific publications are being prepared that complement this paper. They will cite all relevant published work and independent research that was performed to develop the BSF technology. The BSF technology can only improve.

I have eagerly followed (from afar) the implementation and training programs initiated by my students and their students. I have continued to participate, albeit in a comparatively minor way, in the technology transfer process. I have visited many BSF projects around the world and observed how the BSF's were being constructed and used. Several unexpected and problematic innovations were discovered, which in every case were attempts to further assist in the acceptance and ease of dissemination of the BSF technology. Though well intended many of these innovations actually compromised the BSF technology. Training programs can always be improved and with the realization of the potential of the internet I am finally in a position to provide necessary technical support to those who want or need it. The purpose of this paper is to describe the development, knowledge and the present design of *the concrete household BioSand Water Filter* in a manner easily understood by readers who may or may not have advanced training in water treatment engineering. This paper and the others published on the manzwatinfo.ca web site are intended to be a resource on BioSand Water Filter technology that can be easily accessed anywhere in the world.

### **Community Scale vs. Household Scale**

A question frequently asked is "Why a household water filter and not a community-based system?" The answer is that members of individual households living in a truly disadvantaged community will be responsible and take care of a product that they own and helps them whereas they do not usually feel the same sense of ownership and responsibility for a shared community-based system.

Community based projects can be put at risk of collapsing if as few as 10% of participants do not financially support the project. When a community-based project collapses everyone loses – 100% loss of the benefits of the intervention. If the community was using household systems, a 90% acceptance would mean exactly that 90% acceptance, 90% of the community would continue to benefit from the intervention – 10% simply would not use it (for their own reasons). The filters would continue to be used by the target population. It is not uncommon to find 98% of the households in the community using the household concrete BSF.

Community scale systems are often technically more complex, require external energy supplies to operate, require more skilled individuals to implement (instructors and trainers), cost much more than household-based projects (and will never be implemented), and require a high degree of cooperation within the community to be sustainable. A household concrete BSF can be provided one household at a time, require relatively little money and few outside resources. Very large projects can be started slowly by installing a few filters and developing required knowledge and skill sets first. The household BSF technology is very simple to use correctly in a sustainable fashion. BSF projects can be implemented successfully by as few as one dedicated individual.

Community based systems and projects that involve many household systems can also be put at risk if funds are mismanaged. The larger the sums of money being managed the greater the probability mismanagement will occur. Unfortunately, funds must be collected from consumers and properly managed to sustain a community based BSF system, (to hire operators). This is not true when each household has its own BSF and is responsible for its proper use.

When communities are large, more sophisticated or more complex water treatment technologies need to be used larger community based BSF water treatment systems are ideal. Some communities have a culture of cooperation that also provides the ideal environment for community-based systems. Community scale BSF treatment systems can provide a level of service unavailable when individual household filters are used.

There is a role for both household and community based BSF technology. Information is forthcoming as to how to implement community based BSF technology without any violation of commercial interests and patents.

### **Origin and Development of BioSand Water Filtration Technology**

The technology used in the BSF has been described as a variation of '*traditional slow sand filtration*', a water treatment method said to be developed in England in the first half of the nineteenth century. The original slow sand filters were found capable of removing offending particulate matter and substantially reducing or eliminating pathogen hazards. The BSF technology *evolved from knowledge of* traditional slow sand filtration for which there is a vast wealth of know-how pertaining to its use, design and performance developed and well documented over the past one hundred and seventy years. Traditional slow sand filtration could be considered a 'mature' technology by the turn of the twentieth century and is implemented in virtually the same manner to this day.

The BSF technology includes several important innovations not used in traditional slow sand filtration and can correctly be considered a *new fine sand water filtration technology* with treatment capabilities similar to traditional slow sand filtration.

The filtration process used in BioSand Water Filters is known as *'intermittently operated slow sand filtration'* alluding to the fact that the process may be used successfully on a demand basis in contrast to 'traditional' slow sand filtration which needed to be operated more or less continuously to provide acceptable water treatment. (BSF technology should not be confused with intermittently operated sand filters that provide partial treatment of municipal wastewater.)

Filtration of water through fine sand is a very old treatment process that has been used by various societies for several thousand years. Traditional slow sand filtration evolved from those experiences; its utility identified by the apparent health improvement of the people living in communities provided with the treated water. Slow sand filtration as used in large communities could not easily be adapted for household use because of the need for continuous operation – a difficult constraint to overcome. Other types of household sand filters were still considered useful because they removed most of the suspended particles from the water improving its aesthetics; but these filters could not adequately remove water borne pathogens – the water was still unsafe to drink. The concrete household BioSand Water Filter combines all of the treatment capabilities of traditional slow sand filtration with the convenience of use of traditional household sand filters.

### **Performance Objectives Considered in the Development of the BioSand Water Filter Technology**

The development of the BioSand Water Filter technology has considered the needs of the users or consumers of the product, the manufacturers, the various marketing and distribution systems, methods of technology transfer and the nature of project support and funding or financing. It was considered very important to respect the knowledge and views of water treatment specialists and regulatory agencies.

Several objectives were identified and are presented in terms of their association. If all of the objectives were satisfied the water treatment provided by the household BSF technology could be considered:

1. Effective
2. Appropriate
3. Affordable
4. Desirable and
5. Sustainable;

and significantly advance the cause for provision of safe water to the disadvantaged communities of the world.

### **Consumer Objectives**

The objectives of the end user of the BSF, the people who live in the target households, were most important. The BSF needed to:

1. Provide effective treatment to water supplies typically used by the community without using any additional chemicals (or a minimum amount of chemicals) to produce water safe for human

consumption. (Ideally, the BSF would produce water that would meet the drinking water guidelines advocated by the World Health Organization.)

2. Guarantee the production of safe water only (absolutely no possibility of producing unsafe water).
3. Produce adequate volume of water for ten persons, in a reasonable period of time, for drinking, food preparation, cooking, cleaning eating utensils, cleaning utensils used for preparing the food, cleaning surface areas used for eating and for food preparation, and for personal hygiene.
4. Be affordable to the least advantaged in the community (Minimum or no subsidization).
5. Be easily accommodated in the homes of the target community.
6. Be convenient to use by healthy people of normal physical size and health.
7. Accommodate the water use habits of the household.
8. Be easy to use correctly with minimum of training.
9. Be easy to correctly maintain with minimum cost and with minimum training (Preferably no cost).
10. Be robust and difficult to damage.
11. Be easily repaired if damaged.
12. Be locally available.
13. Have local technical support.
14. Have a useful life of ten years or more.
15. Become a desirable household appliance.

### **Manufacturer Objectives**

It was always believed that a condition for the successful introduction of the BSF technology opportunities for local manufacture needed to be maximized. The objectives were to:

1. Design a water filter that could be manufactured locally.
2. Be manufactured using locally available materials.
3. Be manufactured using locally available equipment.
4. Be manufactured using the local labour force.
5. Develop BSF designs that could be easily manufactured with a minimum of flaws and breakage.
6. Be easy to move and transport with a minimum of breakage.
7. Be marketed at a price consumer could afford while making a reasonable profit.
8. Be easily and reliably installed.
9. Required minimum technical support.
10. Be manufactured and marketed in a manner compatible with the local business culture.
11. Design a 'complete manufacturing system' that facilitated 'complete technology transfer' to local manufacturers with minimum of effort and minimum of technical support.

### **Marketing Objectives**

Marketing any technology is a complex process. The word marketing is used rather than donation because it was always believed that the sustainability of any technological intervention would require that the product be affordable to the local population without subsidization. For this to be true the BSF needed to be desirable and affordable to the intended consumer (purchaser). The manufacturer needed to make a reasonable profit. The margin between what the consumers were willing to pay and the price the manufacturer needed to realize should allow local retailers and

distributors who sell directly to the consumer to make a profit. If by some chance the manufacturer and the retailer were the same there was even greater probability that technology intervention would be a success.

The distinction between consumer and beneficiary is very important from the point-of-view of the 'user' of the BSF technology and also from the point-of-view of the providers of the BSF technology. The 'user' is empowered if they can choose, through their own purchasing power, the means with which they are provided safe water – the 'user' has dignity and responsibility. If the 'user' likes the product they will purchase it. If the product is found to be useful users will advocate it. User *opinion* in these circumstances is both valid and important to the successful dissemination of the product. "If my neighbor, who I respect, thinks the product he *purchased* is good, I might seek to acquire it too." In this 'empowered' environment conventional market survey assessments, (usually anecdotal), are appropriate when assessing the utility of a particular technical intervention.

When 'users' are considered 'beneficiaries', they are not empowered and they know this. There is an unbalanced relationship between beneficiary and benefactor. Beneficiaries are not empowered and may feel the unwelcome need to express gratitude whether they truly feel this or not. In unfortunate circumstances the benefactor of the technological intervention may believe that the beneficiary should be grateful for any help they receive. This unbalanced relationship should be avoided wherever possible (except for emergencies and other circumstances of desperation). User opinion in these circumstances is likely not valid.

The manner with which a technical intervention is implemented will determine the success of the intervention as measured using 'market survey' and 'impact assessment' approaches. A successful intervention must consider local manufacture and retailing to a market that sees the benefit of a product they can afford and are willing to purchase (at least pay a portion of the cost), in this case the concrete BSF.

The 'design' of the BSF, including its manufacture, installation, operation, maintenance, and technical support carefully considered the intervention dynamics described.

### **Technology Transfer and Support Objectives**

It was critical to develop a product that functioned well, in all respects, without reliance on continual external technical (or financial) support from agencies or organizations outside of the country and me in particular. First, all aspects of manufacturing, marketing and consumer use should be successful at the local level. 'Local' could mean community, state or country. Second, technology transfer should be very reliable and efficient at the local level. Third, technology transfer should be very reliable and efficient to individuals and organizations who wish to participate in the technology transfer process. The objective was to allow the BSF technology to spread throughout the world by whatever means available. This could only be achieved if the cost for technology transfer and technology support were minimized.

As mentioned, the BSF technology was developed on the basis of accepted science and engineering concepts. Any chance that the technology could be manufactured and used in an 'incorrect' was to be minimized or avoided if possible.

The BSF technology needed to perform consistently well in every circumstance. Performance evaluation of the technology was inevitable, welcome and important to the business communities, donors, implementing organizations, politicians, bureaucrats and regulatory authorities. Satisfactory performance evaluation would ensure that the BSF technology could spread around the globe to wherever it was needed. Poor or inconsistent performance would effectively thwart this objective. The only way to guarantee consistent performance was through consistent technology transfer and appropriate use of the BSF technology.

Technology transfer was always viewed as one of the most important and most difficult of the design objectives that needed to be satisfied.

### **Funding objectives**

There are numerous individuals and organizations that wish to support humanitarian projects of merit worldwide. Each has their own criteria for providing support and has their own ability to contribute.

National and provincial governments and multi-national agencies are particularly sensitive to project optics and have developed certain criteria for assistance, which reflect their political objectives and concerns. Projects that do not meet their criteria simply will not be funded. The problem is that their criteria are just that – their criteria, which may not be considered acceptable or achievable by a great many (most) other funders of BSF intervention projects. Often all an individual or organization wishes to do is provide safe drinking water realizing that this alone will make a tremendous difference to the wellbeing of the people. Issues such as gender equality, religion, participatory development, micro-business development, etc. are very important but not to everyone wishing to support a BSF project.

The ability to enable technology transfer to individuals and organizations who wished to generate their own funding, in whatever manner they wish or are able, to take the BSF technology anywhere in the world was considered a primary objective.

The BSF technology was designed to empower individuals who wished to participate in bringing safe water to the disadvantaged in the world perhaps by funding as few as one filter or as many as they wish or to individuals and organizations who wished to actually perform the technology transfer locally or in any place in the world.

### **Sand-in-a-Barrel Household Water Filters**

Sand-in-a-barrel household water filters have been used for thousands of years in many countries around the world. See Figure 1 below, which shows typical sand-in-a-barrel designs.

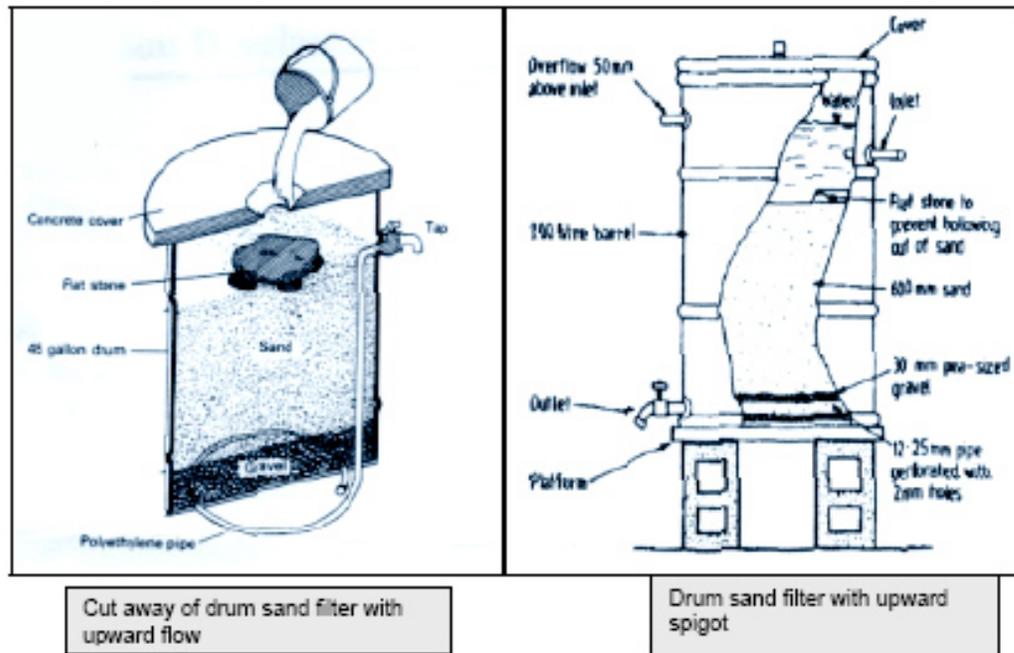


Figure 1. Sand-in-a-barrel filters.

The concept of passing water through fine sand to remove particulate material appears to be intuitive. Many people label fine sand filtration ‘nature’s way’. Rain falls on the soil, filters through the ground (sand) and accumulates in the aquifer and is safe to drink. As elegant as these ideas are, they may simply not be true. The possibility that particulate free, colorless water might not be pure and safe to drink could not be explained until the invention of the microscope and the confirmation of germ theory in the latter half of the nineteenth century.

It is probable that the desire to provide particulate free, colorless water to an entire community in the early nineteenth century lead to the discovery of the impact of fine sand filtration on health. Introduction of community scale fine sand filters resulted in significant reductions in the number of cases of serious water-borne diseases such as typhoid and cholera. The original objective might simply have been to remove offending particulate material from the water so that the distribution pipes remained clear – no one really knows. The water filtration technique using fine sand filters of similar design became known as ‘slow sand filtration’. It is reasonable to hypothesize that the only difference between the successful ‘community scale’ fine sand filter and the ‘household scale’ fine sand filter was that the community scale filter was operated more-or-less continuously in order to insure that treated water reservoirs were kept full. Continuous flow through household fine sand filters isn’t usually practical. Household filters are typically operated on a demand or as needed basis and are allowed to stop and often completely dewater. Even if household sand-in-a-barrel water filters were physically similar to slow sand filters they would still not provide comparable pathogen removal performance

because they were incorrectly operated. It appears that the motivation to provide entire communities with water through piped systems ultimately lead to the 'discovery' of slow sand filtration.

### **Traditional Slow Sand Filtration**

#### History

The health impact attributed to the use of continuously operated fine sand filters to purify urban water supplies resulted in the development of the design of 'traditional slow sand filtration'. The development of the microscope and the association of specific water borne microorganisms with several serious human diseases provided the incentive to build more of the same types of water treatment facilities throughout Europe and the world. Careful accommodation of the numerous engineering constraints inherent to the construction and operation of large capacity water treatment, storage and distribution facilities, that incorporated the successful filtration processes, resulted in acceptable, efficient designs for slow sand filters using the construction technology of the day. Slow sand filtration was a 'mature technology' by the turn of the twentieth century. Standards for construction of slow sand filters have not significantly changed since; hence, the name 'traditional' slow sand filtration. Traditional slow sand filtration has existed for more than 170 years.

#### Description

Slow sand filtration mechanically removes parasites and larger particles but relies on biological processes to remove bacteria and viruses. Rapid sand or pressure sand filtration is characterized by high rates of flow (ten to fifty times that of slow sand filtration) and lack of use of biological processes. Neither of these high-rate filtration processes, operating alone, is capable of removing or deactivating any water borne pathogens. However, water treatment systems that do use the high-rate filtration processes in conjunction with the use of coagulants and clarification are capable of effectively and economically treating raw water of much poorer quality than traditional slow sand filtration and their use became standard despite being more complex and expensive to operate. It is the apparently simple, robust, 'stand-alone', one process water treatment system characteristics of traditional slow sand filtration that are its appeal. It is important to understand the slow sand filtration process to clearly understand its advantages and disadvantages and to understand the filtration process used in BioSand Water Filters.

(There have been quite a number of attempts to modify traditional slow sand filter design, particularly the nature of the media used in the filter. At different times, various forms of activated carbon, zeolite and other adsorbing substances have been introduced and their use even patented; but, all of this family of innovations have ultimately been proven unwelcome modifications and are not used. As well, porous membranes have been introduced and patented in order to simplify slow sand filter maintenance and these innovations have also proved unwelcome and are not used.)

A slow sand filter consists of a column of fine rock 'sand-like' media underlain by two or more layers of coarser rock aggregate that form the underdrain to allow the filtered water to efficiently flow through the filter. See sketch of a vertical section of a slow sand filter in Figure 2. The top most layer of the underdrain is sized to prevent the fine filter media from plugging the underdrain. Water is pooled to a depth of one meter on the top of the filtering media and flows through the media into the underdrain where it is collected and allowed to leave the filter. Particulate material is collected at the interface of

the pool of water and the top of the fine filtering media. The accumulation is known as the 'schmutzdeke', (pronounced *sha - mutz - dek - a* with accent on the second syllable), a German word that means 'dirty blanket'. The schmutzdeke is associated with the ability of slow sand filtration to remove microorganisms and improved ability of slow sand filters to remove particulate material. Slow sand filters are known to remove 100% of parasites, up to 100% of bacteria and viruses and all particulate matter greater than colloidal (clay) sized particles.

Removal of parasites and larger microorganisms (helminths for example) and almost all particulate matter occurs as a result of mechanical straining.

Removal of bacteria and viruses occurs as the result of several processes, one of the most important being 'biological water treatment'. Bacteria and viruses may be free floating, attached to other much larger particulate material suspended in the water or exist in the digestive tracts of much larger organisms (such as protozoan) that also live in the water. Those bacteria and viruses on the larger particulate material or living in the digestive tracts of larger microorganisms will be removed when the particulate material or the larger microorganism is removed. Free floating bacteria and viruses are too small to be 'sieved' or 'mechanically filtered' from the water but some physical removal does occur when the turbulent motion of the water cause them to be jammed into small spaces between particles and into small fissures in the particles themselves. Some of the free-floating bacteria and viruses may attach to the surfaces of the top most part of the fine filtering media and on to the schmutzdeke as it forms – a form of biofilm. Considerable bacteria and viruses may be removed by predation. Organic material, living or dead, captured by the filter become part of the food chain that evolves on the surface of the filtering media and only a centimeter or so into the filtering media. The greater depth of the slow sand filter is credited with the deactivation (loss of ability to reproduce) of viruses. It has been observed that the water must contain significant levels of oxygen above the schmutzdeke for slow sand filters to achieve efficient removal of bacteria and viruses.

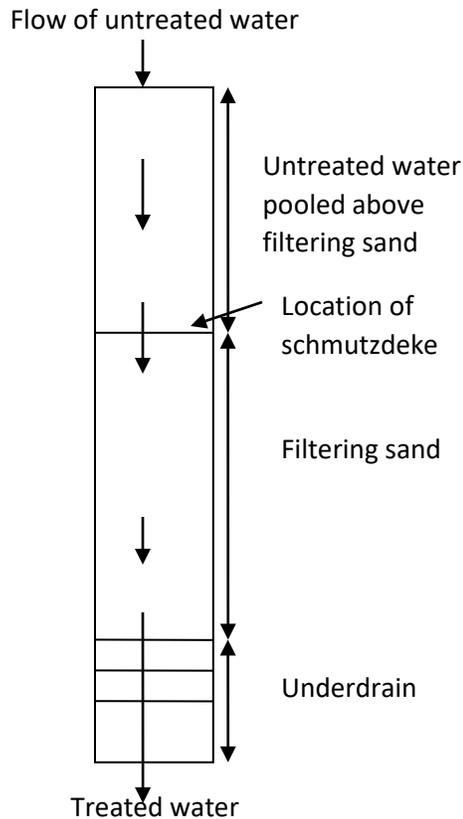


Figure 2. Sketch of vertical section of a slow sand filter that shows the flow of water through the filter.

Specifications for the design and construction of traditional slow sand filters have evolved over the decades of its construction and use throughout the world. Though similar there is considerable scope to advance preferences that may optimize use of local materials, construction techniques, etc. The American Water Works Association and several other organizations have published extensive guidelines on the design and construction of traditional slow sand filters.

The selection of media specified for use in traditional slow sand filters must be of a specific type and size. (For some reason media purity or cleanliness is never specified.) The type of media that should be used for the filtering media is some form of silicate or other material of equal or greater hardness – most important it shouldn't contain any substances that can dissolve and discolor the water as it flows through. (Some soft mud-stones or iron-stones are not useful for use as filter media.) The recommended size (effective size or  $d_{10}$ , which is defined as the size of particle such that 10 per cent of the particles are smaller) of the filtering media is 0.15 – 0.35 mm. It is considered desirable for the individual particles to be close to the same size (uniform in size as determined by the uniformity coefficient, which is defined as the ratio of the size of particle that has 60 per cent of the particles in the sample finer divided by the effective size). A uniformity coefficient of 3 or less is considered desirable. If all the particles were the same size the uniformity coefficient would be equal to one. Determination of effective size and uniformity coefficient will require a 'sieve analysis' performed by a trained technician. Generally, the smaller the effective size and uniformity coefficient the better the filter media will perform. Larger and less uniform media have also performed very well.

The flow rate through the slow sand filter is quite low when compared to other types of sand filtration – hence the name ‘slow’ sand filtration. The flow rate is expressed in terms of volume of water passing through a square meter of filter surface per hour. The recommended flow rate is between 0.1 to 0.4 cubic meters per hour per square meter of filter surface though much higher flow rates have also performed well. Rapid and pressure sand filters have flow rates 10 to 50 times that of slow sand filtration. Consequently, rapid and pressure sand filters are much smaller in surface area than slow sand filtration but they are always used as part of a much larger treatment system; whereas, slow sand filter operate alone.

The effective size of the filter media, the uniformity of the filter media and the flow rate through the filter media together determine the effectiveness of a slow sand filter to remove waterborne pathogens.

As indicated the ability of slow sand filters to remove waterborne pathogens is attributed to the formation of the schmutzdeke and biofilm around particles of filter media near the surface (within 1 cm or so) of the filtering layer. Slow sand filters will remove waterborne pathogens with or without any significant accumulation of organic debris on the surface of the filtering media; that is, there may be no apparent schmutzdeke. It is generally accepted that the particles near the interface of the filtering media and the water become colonized by bacteria that are particularly effective at capturing, consuming or otherwise deactivating waterborne microorganisms in the water as it circulates around the particles. It is also apparent that the flow of oxygen laden water through the surface of the filter media must be more-or-less continuous or the filter performance will reduce to levels observed when the filter was commissioned (around 60%). It may be concluded that the schmutzdeke and the biofilms formed on the individual particles are populated by organisms that require oxygen to survive; that is, the organisms are aerobic. If the flow of water through the filter is stopped for as little a one- or two-hours aerobic microorganisms will adjust to minimum activity – go dormant or die. When the flow of water is restored the filter will regain its ability to remove bacteria and viruses within twenty-four hours.

Aerobic biological activity will not continue into the slow sand filter much below the surface of the filtering media. First there should be no food for the microorganisms if the filter media was clean and second, there is insufficient oxygen for aerobic organisms to survive.

The formation of the schmutzdeke and the biofilms require time to accumulate and develop their capacity to remove bacteria and viruses. Larger organisms such as the cysts of parasites and larger are removed by mechanical processes that do not depend on the formation of a schmutzdeke or biofilm. These larger organisms will be removed at all times. The removal of bacteria and viruses is in the 60% range gradually increasing to close to 100%. The time required developing the maximum bacteria and virus removal capacity is known as the ‘ripening period’.

Anaerobic biological activity can occur if media becomes coated or otherwise contaminated with organic material that is a ‘food’ for anaerobic microorganisms such as colliform bacteria (also aerobic), which survive very well in the gastrointestinal tracts of mammals and birds. Slow sand filters should be constructed with media that is clean and free of all forms of organic materials. Filters constructed using media that is not clean will develop bacteria colonies within their media and these filters will exhibit bacteria concentrations in the produced water greater than those observed in the unfiltered water. Their ripening period will be somewhat longer – until the bacteria consume all of the available food.

After a period of use the schmutzdeke and organic and inorganic accumulations of particulate material in the top surface of the filtering media will reduce the flow rate through the slow sand filter to unacceptable levels. The slow sand filter will not exhibit 'breakthrough', the phenomena where untreated water can pass through the filter dangerously untreated. (Note that rapid and pressure sand filters do exhibit breakthrough.) As the upper layers plug off and the flow decreases the quality of the treated water actually improves. "The last drop produced by the filter is the best drop!" Slow sand filters cannot produce unsafe water unless the water being treated is very contaminated (quality near that of wastewater) in which case disinfection would resolve the 'safe water' problem or there are serious design and operational flaws.

Typically, the flow rate through the slow sand filter is restored by dewatering the filter and physically removing the schmutzdeke and the upper 1.5 to 5 cm of filtering media. The ability of the filter to remove bacteria and viruses will be restored within one or two days of cleaning (compared to two or more weeks required for the original filter ripening). Note that the removal of the upper layers of filter media, also known as scraping or cleaning, does not impair the ability of the slow sand filter to remove parasites or most particulates (the formation of a schmutzdeke does improve the ability of slow sand filter to remove very fine particulate material). The process of scraping is obviously quite labour intensive. Slow sand filters are constructed with deep layers of filtering media to allow for several scrapings before new, clean filtering media is required – flow rates through these slow sand filters will usually be lower than when initially filled. For this reason, the use of slow sand filters is not recommended when the untreated (raw) water supply contains too great a concentration of suspended particles.

A compliment to scraping, used to minimize frequency of scraping, is known as 'harrowing'. When the flow rate is too low the surface of the filter is harrowed or agitated using a tool that resembles a rake. The material that is causing the reduced flow rate (some of it) is suspended in the water above the filter bed and is drained to waste. This process can be repeated several times before the filter will require an actual scraping. It has been observed that the ability of slow sand filters to remove waterborne pathogens is not impaired (even for a moment) by the harrowing procedure.

Some important facts and observations regarding traditional slow sand filters:

1. Traditional slow sand filtration (SSF) is an engineered, widely accepted water treatment technology.
2. SSF is effective in removing waterborne pathogens and particulate material (larger than colloids or clay sized particles).
3. SSF's will always remove parasites and particulate material from water.
4. Slow sand filters (SSF's) are simple to design, construct, operate and maintain.
5. SSF's must be operated continuously to ensure aerobic layers near the surface of the filter media receive oxygen necessary for survival.
6. The depth of filtering media in a SSF responsible for removing waterborne organisms from water is usually not more than 1 cm.
7. The biofilm that coats the particles at the top of the filtering media is responsible for bacteria and virus removal – the formation of a schmutzdeke is not necessary for SSF's to develop this capacity.
8. Dissolved oxygen concentrations within the filter media are below those required for the survival of aerobic bacteria.
9. Virus deactivation requires a certain depth of media – not specifically known but a depth of 40 to 45 cm is considered a minimum depth.

10. The removal of the upper layer of filtering media of a SSF significantly impairs the performance of a SSF until the biofilms are reformed on the media particles near the surface of the filtering media.
11. SSF harrowing can provide a very effective means of filter cleaning without impairing filter performance.
12. SSF's should be constructed using very clean media or their performance during initial periods or performance will be seriously impaired. (They will recover eventually.)
13. Traditional SSF designs are very large, civil engineering works
14. SSF's are NOT appropriate for household applications because they are large and must be operated on a continuous basis.
15. Traditional SSF's are only practical if the water being treated has low concentrations of suspended solids because the cleaning process is cumbersome and very labour intensive.

## **BioSand Water Filter Design**

### History of Development

The design of the concrete household BioSand Water Filter was developed after a thorough review of published papers, texts and design manuals of traditional slow sand filtration and the review of published accounts of numerous other types of household sand filters that have been used to treat water in households throughout the world for thousands of years. The development of the concrete household BSF technology has also benefited from the critical reviews and constructive comments of several individuals who have participated in the implementation of the technology worldwide. The present design may be modified to accommodate local conditions or opportunities for construction improvement; however, the changes must be carefully implemented so as not to compromise the fundamental principles that allow the BSF technology to treat water as well as it does.

“Every square centimeter and every cubic centimeter of the BioSand Water Filter has been carefully designed! Ad hoc, poorly thought-out modifications to the BSF technology, including its manufacture can damage or impair BSF performance in unpredictable ways and the reputation and use of a very effective water treatment technology seriously compromised. The BSF technology that has proven so successful worldwide is based on the descriptions of the BSF technology presented in this paper. Any change to the design, construction or use of the BSF technology should be carefully reviewed in light of the design principles presented in this paper and trained professional knowledgeable in field of water treatment and fine sand filtration in particular.”

The BioSand Water Filtration technology, as used in the design, construction, operation, and maintenance of the concrete household BSF, is based on careful consideration of the intended purpose of the household BSF and the science and engineering incorporated in both the sand-in-a-barrel and traditional slow sand filtration water treatment technologies. Consider Figure 3 which illustrates a cross-section of a concrete household BSF.

### Description

The concrete household BSF consists of a concrete vessel approximately 1 meter in height and 40 cm in width. This height is convenient for use by most adults worldwide. The filters do not occupy much space though they should be located in a protected environment away from animals, the climatic elements and vandalism. The interior is divided into three volumes that contain, the filter media

(filtering media, separating media and underdrain), paused water (water that remains on top of filtering media when flow from filter stops), and raw water chamber (includes entire volume above surface of paused water surface). The depth of the paused water is approximately 5 cm. The depth of sufficiently shallow to allow oxygen from above the water surface to reach the biolayer on the surface of the filtering media but deep enough to absorb the impact of the untreated water when it is initially added to the filter. The volume of the raw water chamber is approximately 20 liters (the amount held by a typical large plastic bucket). The filtering media is approximately 45 cm deep. The separating media is 3 to 5 cm deep. The underdrain is sufficiently deep to cover the inlet to the bottom of the standpipe by 2 cm of material.

The walls are thick enough to cover the standpipe by at least 1 cm of concrete. This thickness ensures that the concrete will be sufficiently thick and will not develop cracks along the length of the standpipe.

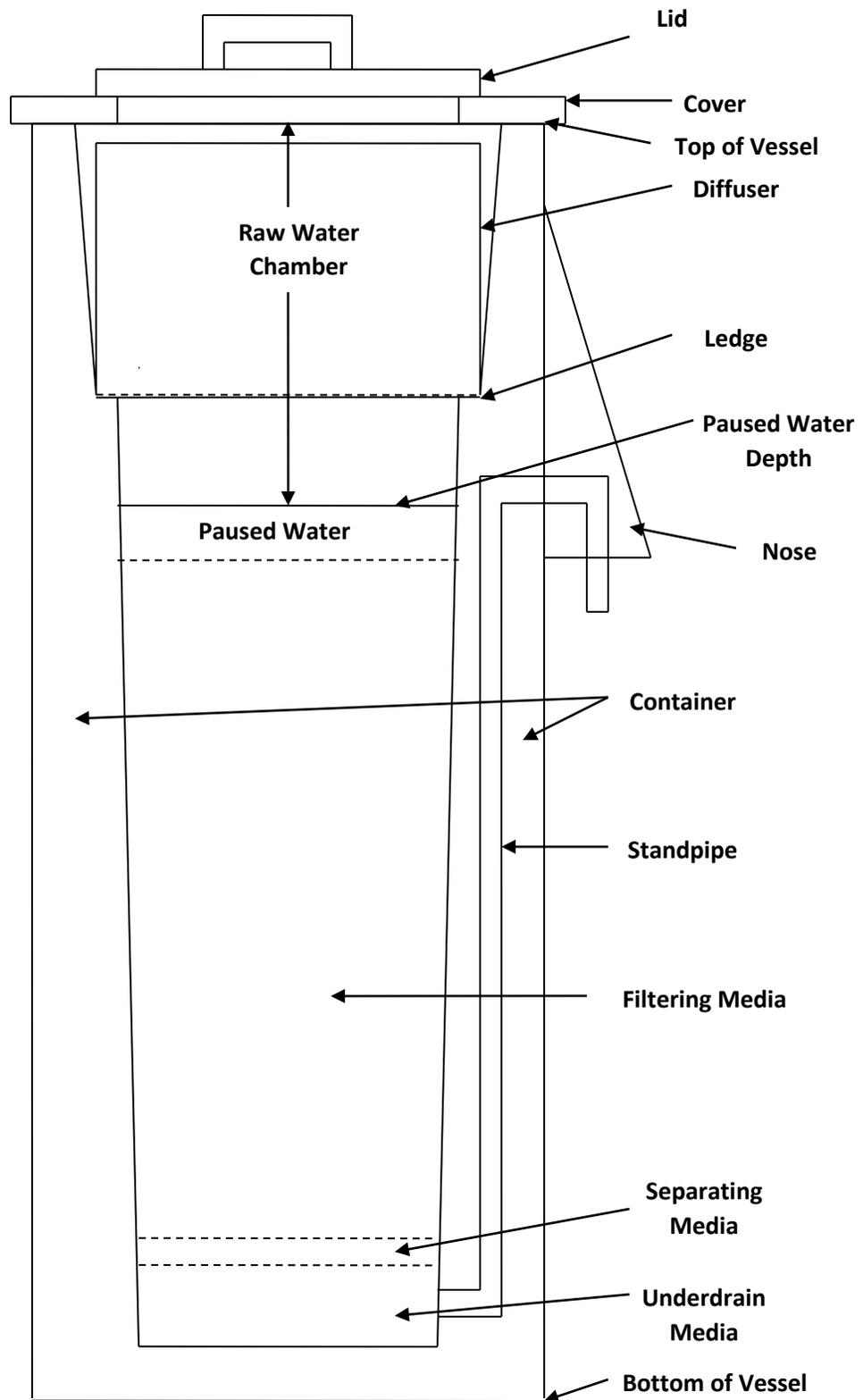


Figure 3. Cross-section of concrete household BioSand Water Filter.

The standpipe is completely covered with concrete and the outlet is protected by a protrusion known as the 'nose'. There is no opportunity for the standpipe to be damaged unlike the design shown in Figure 4.

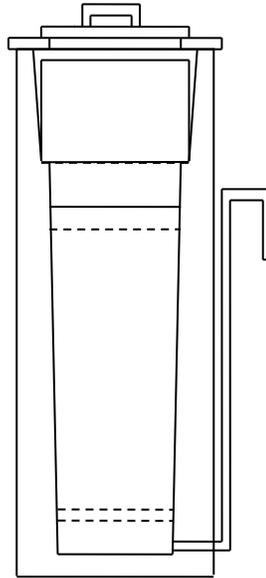


Figure 4. Cross-section of concrete household BSF with plastic standpipe incorrectly installed outside of filter body.

The interior walls of the vessel are tapered from the bottom to a height approximately 5 cm above the paused water surface. The walls abruptly thin to approximately 2 cm and are tapered much more gradually to the top of the vessel. The resulting ledge is approximately 2 cm in width. The width of the interior of the filter above the ledge is approximately that of a typical 20 liter plastic bucket. The tapered walls permit easy removal from steel molds used to manufacture the vessel.

The concrete walls, nose and base do not contain any steel reinforcement. The concrete is produced using a mixture of one part Portland cement, one part clean fine sand and one part coarse aggregate (approximately .6 cm to 1.2 cm in diameter). The maximum diameter of the coarse aggregate must be carefully adhered to or the concrete will not form around the standpipe. Less Portland cement can be used provided ultimate strength of concrete allows safe handling, doesn't develop cracks and allows convenient manufacture. The concrete is made without use of any additives that add expense and may not be available.

The standpipe is constructed of ½ inch (approximately 1.25 cm) inside diameter PVC pipe. The inlet to the standpipe is located on the bottom interior of the concrete vessel. The outlet of the standpipe is located on the bottom of the vessel nose. The outlet extends at least 5 cm beyond the bottom of the nose to ensure that the water leaves the filter cleanly in a downward direction even at very low flows. The use of ½ inch PVC insures that at a flow rate normally associated with a household concrete filter of between 40 and 60 liters per hour, sufficient air will be allowed into the standpipe (at the outlet) to prevent any siphoning action that would tend to dewater the vessel (a phenomena that has disastrous consequences on filter performance). Note that there is NO VALVE on the filter outlet and there never should be a valve or any other device that prevents free flow of water from the filter standpipe. The filter must be allowed to freely drain to the depth of the paused water on the surface of the filtering media. If the paused water depth is too great the biolayer may be deprived of oxygen and die and the performance of the filter seriously impaired. The PVC pipe does not go through the wall of the vessel to avoid the use of complex and possibly expensive water stops that prevent water leakage between the outside walls of the pipe and the concrete. The elbows may be purchased separately or formed by cutting the pipe at a 45-degree angle and heat welding. The pipe material may be different than PVC but must be safe for use with food. Locating the standpipe within the concrete wall in the manner described ensures that it is adequately supported and protected without any danger of cracks forming over the standpipe on either the inside or outside walls. (Because water can flow between the outside of the pipe and the concrete, interior cracks might allow short circuiting of untreated water to the standpipe outlet.) The standpipe MUST be adequately covered with quality concrete.

In various designs of household BSF's a flow restrictor was used at the inlet to the standpipe or a short distance along the standpipe at the bottom elbow. The flow restrictor consisted of a thin plastic disc with a small hole in the center. The idea was imperfect. It really only helped control the flow if the media was already very close to being correctly prepared. As mentioned in the guidelines for media preparation the final 'tuning' of an installation is more easily achieved by adding or subtracting 'fine' media at the top of the media layer itself at the time of installation.

Note that the standpipe does not rise vertically inside the filter vessel in the media and then out of the filter as shown in Figure 5. This is NOT A GOOD design because there is significant risk that any slight jar to the standpipe will allow untreated water to drain down the outside of the standpipe and contaminate the treated water. This might be a minor risk with a concrete vessel but it is a significant risk when the vessel is plastic.

The different layers of media must be produced from clean supplies – preferably crushed rock obtained from a quarry. Three- or four-layer systems may be used. See papers describing the media selection and preparation process and the techniques used for installation and maintenance titled, 'Guidelines for Preparation of Media for the BioSand Water Filter – Three Layer System' and 'Guidelines for Preparation of Media for the BioSand Water Filter – Four Layer System'. These guidelines must be carefully followed. The filtering media produced tends to be much smaller in size than that specified for slow sand filtration. A third publication titled 'Guidelines for Preparation of Media for the BioSand Water Filter When There is No Crushed Rock' may also be useful.

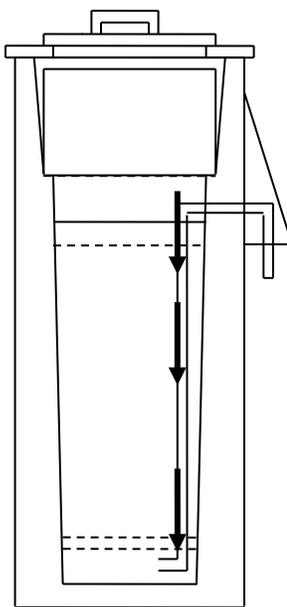


Figure 5. Cross-section of concrete household BioSand Water Filter with INCORRECT standpipe.

The recommended depth of the filtering media is 45 cm or more to allow almost complete deactivation of viruses. Depths of more than 1.5 meters have been suggested, which if implemented would result in household filters much too tall to be practical. The specifications for the selection and preparation of filtering media, separating media and underdrain for use in BSF's is much more stringent, in many respects, than those used to specify filtering material, etc. used in traditional slow sand filtration. The fact is that the depth of the filtering media, determined on the basis of providing the same virus removal or deactivation, is unique to each *filtering media* that might be used. The specification for selection and preparation of filtering media does not mean that each carefully prepared filtering material will perform the same, at least as it relates to virus removal and deactivation. The specifications are not that exact. It is not practical to develop general guidelines for the preparation and use of all variations of filtering media. Specifications for one filtering media can not be expected to apply to any other filtering media. The only guarantee that viruses will be removed deactivated or killed; that is, to ensure that there are no viruses in the water that can infect humans, is to **disinfect the filtered water**, a process that is common and can be performed very easily and economically by intended consumers worldwide.

BioSand Water Filters do not incorporate layers of zeolite, granular activated carbon or any other material. These materials might perform very useful functions in terms of improving the quality of the treated water; but it is not practical to mix them, in any way, with the filtering media used in a BSF. Without periodic testing it would be difficult to determine if these other materials were performing as intended and needed replacing. The inclusion of filtering media that will perform in an uncertain fashion and will require periodic replacement is contrary to the design philosophy of the BSF. BSF's do

not require periodic testing to determine if their ability to treat water has diminished – their ability to treat water actually improves with use. BSF's require cleaning when the production of treated water decreases to unacceptable levels and then they are easily and quickly cleaned without incurring the expense of media replacement. If treatment using zeolite, granular activated carbon, etc is desired these should be included in separate pieces of equipment that can be used after filtration is completed where they can be maintained as required without interfering with the normal operation of the BSF technology.

The tapered inside walls eliminate any chance of short circuiting.

The purpose of the diffuser is to break the impact of the water when it is poured into the top of the vessel so as not to disturb the surface of the filtering media. A biolayer forms on the top surface of the filtering media when water containing microorganisms (including pathogens) is treated using the BSF. The biolayer must cover the entire top surface of the filtering media. Portions of the top surface that do not develop a biolayer will cause inadequately treated water to be produced. Several diffuser designs are available that eliminate this problem.

The diffuser is a container with holes on the bottom that sits on the ledge about 5 cm above the paused water surface. The holes are .3 mm (1/8 inch) in diameter and spaced 2.5 cm (1 inch) apart on a square grid across the entire bottom of the diffuser. The exact size of the holes and their spacing were determined through careful research. Holes that are too large will permit jets of water to penetrate the paused water depth and disturb the top surface of the filtering media and the biolayer. If the holes are too close together the resulting streams of water combine to form larger high energy jets that can also penetrate the paused water. The size of holes recommended permits the maximum flow through the diffuser using the biggest and least number of holes. Rapid flow is desirable from the standpoint of the individual pouring water into the top of the filter – they wish this to take as little time as possible. The top of the diffuser should extend as close to the top of the vessel as possible. The diffuser shown in Figure 2 is made from a 'cut-down' plastic bucket with holes drilled on the bottom. There are several other very good diffuser designs that all ensure that the top of the filtering media will not be disturbed when water is added to the filter. The least effective design (not recommended) is a simple perforated flat plate that sits on the ledge as there is almost always leakage around the plate edges that result in scouring of the surface of filtering media and unpredictable filter performance. (The significance of lack of attention to the importance of a close-fitting diffuser and filter performance was demonstrated in a paper that published an evaluation of the BSF to remove bacteria. The diffuser used did not fit and allowed scour of the biolayer to occur and the performance measured was in the 90% range instead of the typical 99% per cent range found in most other laboratory evaluations.)

The filter vessel uses a cover that extends across the top of the vessel and contains an opening that is covered by a lid. The edges of the opening in the cover overlap the edges of the diffuser by a least 2 cm. The lid adequately covers this opening. Untreated water is added to the filter by removing the lid and pouring water through the opening. If properly designed all of the water added to the filter will enter the diffuser without any chance of disturbing the surface of the filtering media.

It is apparent that there is a close relationship between the design of the diffuser and the design of the lid. A diffuser is always required. Care must be taken to never allow untreated water to by-pass the diffuser and scour the top of the filtering media. Scour of the surface of the filter bed results in the removal of the biolayer if it forms at all. Untreated water passes through the scoured area and overall

filter performance can be significantly degraded. The filters always need a cover and a lid or a large lid that eliminates the possibility of debris falling into the filter vessel itself.

The vessel is heavy weighing nearly 150 kg. It is a little fragile though and must be handled carefully.

The BSF is used to produce water safe for drinking. It is imperative that all materials used in its construction are suitable for production of water safe for drinking. Care must be taken to use only those materials that will not generate or otherwise give off toxic substance. BSF manufacture should ensure that the final product and components, such as the media, be carefully disinfected and protected from contamination. Installation procedures must be performed using techniques that minimize opportunities for contamination of any of the filter components or media.

Training courses are provided which provide exact descriptions on how to manufacture concrete water filters and their use.

### Operation of Household BSF

The operation of the household concrete BSF is very simple and is described as follows:

1. The lid is removed.
2. Raw (untreated) water is poured through the opening into the diffuser. The water gently falls into the surface of the paused water gradually filling the entire raw water chamber.
3. The water flows through the filtering media into the underdrain, up the standpipe and into a receiving container.

The filtered water is safe to drink. Disinfection of the filtered water using dilute solutions of sodium hypochlorite (unperfumed household bleach) is recommended. Dosages should be such that the water *just* smells of chlorine after the bleach is added. This ensures that all of the other 'stuff' in the water that would react with the chlorine has 'reacted' and there is chlorine available to kill any potentially offending bacteria and viruses. Remember that 100% of the parasites have been removed. The foul taste and odor associated with use of sodium hypochlorite will dissipate with time and exposure to air.

World Health Organization guidelines for drinking water indicate that there MUST be zero coliform bacteria in water suitable for drinking. The criteria are very conservative especially when considering water treated by slow sand filtration. Many people (most) around the world will not put any bleach in their drinking water – they think it is tantamount to poisoning themselves. Nevertheless, these same people seem to benefit as much as those who do use bleach by using the BSF technology.

### Details of Filtration Process

The filtration process used by the BioSand Water Filter may be considered a variation of slow sand filtration that allows the filter to be used on a demand basis. The effective size and depth of the filtering media are used to control the flow rate of water to no more than 600 liters per hour per square meter of filter surface when the filter raw water chamber is completely filled with water. In the case of the BSF the depth is fixed so it is the effective size of the filtering media that governs flow rate. The filtering media used in a properly constructed BSF ALWAYS meets or exceeds the specifications for effective size and uniformity coefficient for traditional slow sand filtration.

When water containing microorganisms is treated using the BSF a schmutzdeke (accumulation of organic and inorganic debris) may form on the surface of the filtering media and a biofilm will start to form on each of the particles near the surface of the filtering media. Similar to traditional slow sand filtration the schmutzdeke and the biofilm will remove virtually all of the parasites, bacteria and viruses.

Unlike traditional slow sand filtration BSF's may be used on a demand basis or on a continuous basis. This very important characteristic is achieved by allowing the water in the raw water chamber to decrease to the paused water level between uses; that is, between times when water is actively being filtered. The depth of the paused water is controlled by the location of the standpipe outlet – they are the same. The depth of the paused water is sufficiently small that oxygen from the air above the water can diffuse through the water to the schmutzdeke and biofilms and keep them alive and active even when water is not being filtered and ready to perform when water is being filtered.

It is very important that the water be allowed to freely drain until the water level in the raw water chamber decreases to the paused level.

### Installation and commissioning

The household concrete BSF is an important new appliance for a family. It should be conveniently located in the home or apartment (usually the kitchen) where it is protected from the environment, animals and the environment. Even in the home care must be taken to avoid contamination from pets and small children. Once the vessel has been located it should be checked for debris and should be wiped free of dust.

The filter media is quite clean but it is not sterile. The filter media will 'clean-up' during the commissioning process. Nevertheless, care should be taken not to contaminate the media when handling and storing it prior to installation.

The underdrain media is placed first, followed by the separating filter media and then the filtering media (the filtering media may be comprised of one or two layers). Often more media is provided with the filter than is required to account for variability in packaging and possible spillage. Homes are often quite remote from manufacturing and distribution centers and insufficient media at time of installation can be a very inconvenient circumstance.

The media installation MUST follow the instructions provided EXACTLY as written. Sloppy or incorrect installation can result in flow rates that are too high or too low. The filter may actually not produce water at all. It is very difficult to predict what is causing the problem and the solution is often removing the media one layer at a time and reinstalling it more carefully. Media installation is described in detail in the publications Guidelines for preparation of media for the BioSand Water Filter – three-layer system and Guidelines for preparation of media for the BioSand Water Filter – four-layer system; but the instructions that MUST be followed are those provided by the local manufacturer. The water used during media installation may be the very same water that will eventually be treated. The water may become quite turbid as a consequence of suspending the finest particles in the water. This is not a problem – the finest particles are required to provide correct filtration. The turbid water does interfere with the media installation procedure since it is difficult to know the depth and condition of the media that has been added. Strategies are available to overcome this problem. Immediately after all the media has been installed, the filter is commissioned.

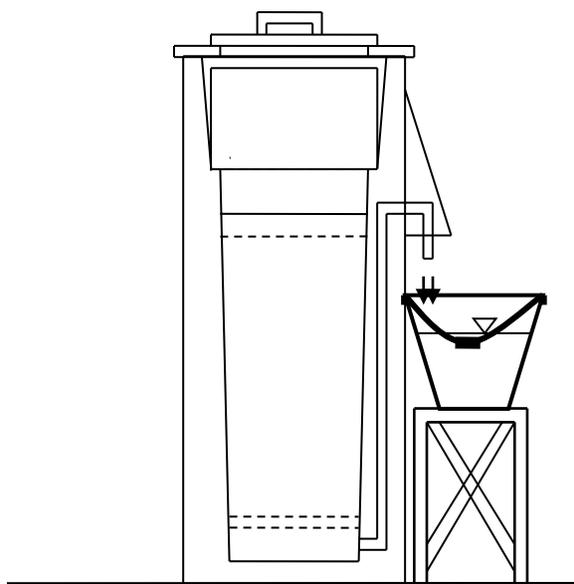


Figure 6. Concrete household BSF producing water into a bucket.

Commissioning consists of rinsing the media by pouring several buckets of untreated water into the filter followed by disinfection of the standpipe and underdrain media. Filter set-up and operation is shown in Figure 6. At the start of the rinsing process, the water leaving the standpipe, the filtered water, will be quite turbid. The media is being flushed of all very fine particles. Normally, after a few buckets of water have been filtered, (the exact number will vary with the nature of the media used), the filtered water will become very clear. There may still be colour and this due to the presence of dissolved organics in the water. This is not a health problem in itself; but, if the water is disinfected with bleach, unwelcome toxins known as trihalomethanes (THM's) will form. The drinking water guidelines published by the World Health Organization (WHO) indicate the maximum concentration of THM's that should be found in water.

Interestingly, the WHO recommends disinfection of water using bleach even if the water is not filtered. I do not recommend this because the disinfection will not be effective on many encysted parasites or microorganisms that can 'hide' within the particles in the water. The BSF will remove almost all of the particles and all of the microorganisms that cannot be killed by the bleach. Much more bleach will be required (to achieve treated water that smells slightly of chlorine) and much more THM will be formed in the process.

A more problematic circumstance occurs when the raw water supply contains colloidal sized particles such as clay. The BSF will not remove these particles without pretreating the water with coagulants and the water will definitely not meet WHO guidelines for turbidity; that is, the filtered water will still look cloudy. When coagulants are added to water (usually some form of aluminum or iron salt) larger particles known as flocs will form. The flocs capture the colloid sized particles and are easy for the

BSF to remove. The BSF may require more frequent cleaning; but, this does not impair filter performance. Coagulants are not expensive but are not usually available. Consumers are usually reluctant to add any kind of chemical to the water and typically they do not do a very good job adding chemicals unless very robust procedures are introduced to remove any chance for subjective behavior. The quality of the 'cloudy' filtered water is still very good because waterborne pathogens are still being removed. The colloids are smaller than the smallest of the water borne pathogens and must be removed by some form of mechanical process. The pore sizes in the filtering media are just too large to sieve colloidal particles from the water. The microorganisms are removed by biological processes that are not affected by the presence of the colloids and the microorganisms cannot attach or live on the colloidal sized particles because the particles are too small.

(Note regarding turbidity: Turbidity increases when the color of the water increases and when the number of particles suspended in the water increases. Turbidity is measured using special equipment known as turbidity meters. The WHO drinking water guidelines clearly specify maximum levels of turbidity and water with turbidities that exceed their guidelines is considered unsafe for human consumption. Clearly, there are circumstances where this is not so.)

The production of water from the BSF should be determined during the rinsing process using a bottle or container of known volume and a watch with a second hand. It is very important that the flow rate not exceed manufacturer's specification (plus or minus 10%). Recall, the flow rate is determined when the filter is completely filled with water.

Once the filtered water runs clear or as clear as it is going to be a dilute solution of household bleach is poured into the standpipe outlet using a special U-shaped tube that attaches to the filter outlet (See Figure 7.). Sufficient disinfecting solution (about 1 or 2 liters) is poured into the standpipe to disinfect the standpipe and underdrain gravel. One or two additional buckets of water are poured into the filter to flush the chlorine solution out and the filter is ready for use.

With use over a period of one or two weeks depending on the concentration of microorganisms in the untreated water poured through the filter a biolayer is formed. The biolayer includes the layer of particles near the top of the filtering media that develop a biofilm over their surface and the schmutzdeke if the one is formed.

The **biolayer will form naturally**, *without the addition of any other substances*, provided the water contains living microorganisms that form biofilms. Experience indicates that all-natural occurring water that contains microorganisms will form a biolayer.

No other substances should be added to the surface of the media layer or included anywhere else in the media used in the BioSand Water Filter, including inorganic coagulants or organically derived coagulants such as those derived from the meringa seed. Inclusion of charcoal layers or layers of granular activated carbon or zeolite should be avoided. It is very important that the media in the BioSand Water Filter be selected as described in preceding discussions. Inclusion of any of these layers would detrimentally impact on the performance of the BSF. In fact, filter systems which include these modifications should not be considered acceptable variations of the BSF technology.

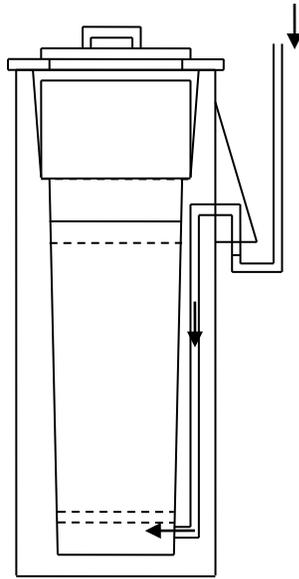


Figure 7. Household concrete BSF with disinfection U-tube attached to outlet of standpipe.

#### Water storage

Filtered water should be captured in a clean, adequately sized storage container. Ultimately, the filtered water will need to be dispensed and the storage container may have provisions to safely do this. Dispensing filtered water using a dipper or cup should be avoided because of the risks of re-contaminating the water. Filtered water should be protected from dust, insects and other forms of potential contamination. Often consumers will not use another clean bucket to capture and store the water but will use a jug like container with a very small inlet and a feature for dispensing the water. This type of container is not easy to use with the outlet provided by the BSF. The water that flows and ultimately drips from the standpipe is difficult to catch the ‘dribbling’ water using a container with a very small opening.

(An idea that has been used to control ‘dribbling’ is to put a 90-degree elbow on the bottom of the outlet pipe. The dribble changes from a very wild rotating pattern to a straight vertical one that can be easily controlled.)

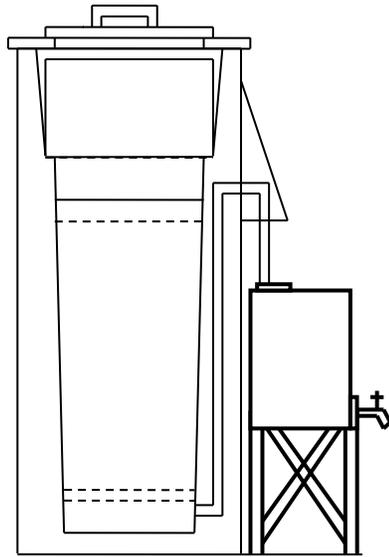


Figure 8. Concrete household BSF with dispensing container and extended standpipe outlet.

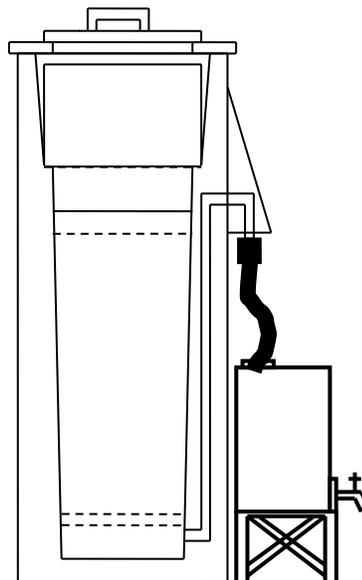


Figure 9. Concrete household BSF with dispensing container and flexible hose connecting standpipe to inside container.

Consumers and manufacturers have developed very ingenious solutions to this problem. One solution consists of extending the length of the pipe from the standpipe outlet to where it can be inserted directly into the small opening (See Figure 8.). Another solution consists of attaching a pipe to the standpipe outlet and inserting the pipe directly into the clean water container that may now be some distance away (See Figure 9.). The danger with both of these solutions is that the standpipe may completely fill with water, (including the horizontal section in the nose and the vertical portion of the outlet), and water will flow from the filter by siphoning action. Siphoning should definitely be avoided for the following important reasons:

1. It will cause increased flow rate from the filter that may diminish filtered water quality.
2. The filtering media may compact. Pore sizes in the filtering media will be smaller and flow rates observed during correct, normal filter use will be too low.
3. The siphoning action may dewater the filter such that there is no paused water on the surface of the filtering media. This would seriously damage the biolayer and the ability of the filter to remove bacteria and viruses.
4. Once dewatered the filter media may draw in considerable air. When water is added the resulting air binding may seriously decrease flow through the filter. (Note that this can be eliminated by adding water through the filter outlet using a device similar to that used when disinfecting the filter as part of filter commissioning.)

Siphon breaking can be achieved by inserting a siphon breaker as shown in Figure 10. The siphon breaker must extend upward above the top of the raw water chamber and then turn downwards to avoid the chance that foreign material may fall into the outlet and contaminate the water. As well a small screen should be placed over the opening to prevent insects from entering and colonizing the siphon breaker itself. A similar device may be used with a flexible hose. Note that the siphon breaker is open at the top with the opening facing downward. This device appears awkward but it does eliminate the risk of siphoning.

An alternative method for siphon breaking is to drill a very small diameter hole in the outlet pipe at the point where the pipe leaves the filter nose toward the front of the pipe. A problem that might be experienced is that a very small amount of water may leak from this hole but this would be unlikely if ½ inch PVC pipe is used.

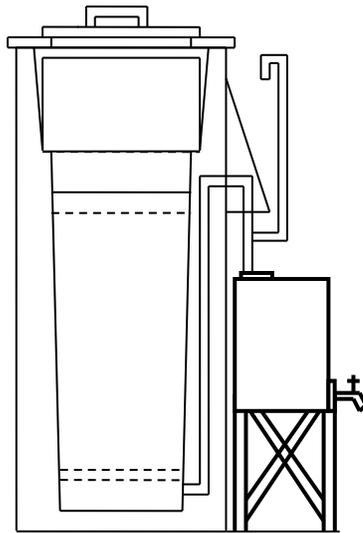


Figure 10. Concrete household BSF with dispensing container, extended standpipe outlet into container and siphon breaker.

#### Cleaning (maintenance)

With time and use the surface of the filtering media will accumulate inorganic and organic material that will plug the pores and decrease the flow rate through the BSF. The BSF does not exhibit breakthrough of untreated water – it cannot – the flow gradually decreases as the pores are plugged. Untreated water is not forced through that portion of the filter media responsible for treating the water. In fact, as the flow through the BSF decreases the quality of the filtered water increases. When the production of filtered water is unsatisfactory (too low) it is time to clean (maintain) the filter media. This is a simple process that is performed as follows:

1. The raw water chamber is filled approximately one-half full with the diffuser in place.
2. The diffuser is removed.
3. The surface of the filtering media is vigorously agitated with your hand or using a brush. At no point are the fingers or the utensil ploughed into the media any deeper than the upper 1 cm. (Recall only the upper centimeter or so is actually plugged.) Rapid movement of fingers across the surface of the filtering media will cause a turbulence that will agitate the media to a depth of at least 1 cm.
4. The filter sand is allowed to settle – occurs in a few seconds.
5. The water containing the suspended material is removed with a ladle or cup.
6. The surface of the filtering media is leveled.
7. The diffuser is replaced and the filter is ready for use.

If the flow rate has not satisfactorily recovered the cleaning procedure can be repeated.

Note that media is not normally removed and new media is never required. The media is in effect ‘cleaned in place’. This system of cleaning works very well because the biofilm surrounding each

of the particles that comprise the top 1 cm or so of the filtering media is not removed as it is when traditional slow sand filters are cleaned (the top layer is actually removed). It is interesting to note that a simplistic variation of this form of cleaning of slow sand filters is known as 'harrowing' and is only minimally successful and still very labour intensive.

Rigorous deep agitation of the filter media during cleaning, where the fingers are deeply immersed well into the media (more than 2 cm) can temporarily impair filter performance (for a day or two). This is because the stirring action deeply buries many of the particles with the attached biofilm and brings particles without the biofilm to the top. The effect is similar to the scraping technique used to clean traditional slow sand filters though not quite as severe. The performance of a deeply agitated filter will recover once a biofilm forms on the newly available particles.

There may come a time when the 'clean-in-place' procedure does not result in adequate recovery of the flow. When this happens approximately 5 cm of the filtering media should be removed, washed thoroughly in a bucket to remove all of the particulate material, and then replacing it into the filter. The ability of the filter to remove bacteria and viruses will be diminished but will fully recover in one or two days of use.

#### Manufacturing considerations

It has taken almost 20 years to develop the present design of the household concrete BioSand Water Filter and associated manufacturing system. Manufacturing with good quality control was always considered important to insure performance consistency. This remains a particularly challenging objective in the difficult manufacturing circumstances typical of disadvantaged communities worldwide and the limited technical skill of the individuals who are expected to become 'filter technicians'.

Several concrete forming and casting techniques were tried but the use of steel molds was selected as method of choice for forming the concrete vessel. The design of the concrete vessel ultimately accepted was the result of eight design reviews that involved the construction of eight steel molds and considerable experimentation. The steel mold that is presently recommended can be manufactured anywhere in the world in steel fabrication shops that contain only the minimum equipment required to 'cut, paste and drill' steel. Tools required to manufacture the molds include an oxy-acetylene cutting torch, grinders, polishers, welders and drills. Mild steel materials include plate, angles and tubing and steel bolts. High quality shop drawings have been prepared and have been used on several occasions in Canada, Latin America, the Caribbean, Asia and Africa. These drawings are made available after required training is completed.

The concrete vessels formed using the steel mold will conform to the BSF design described earlier. It is not essential that all BSF's use exactly the same design but it is important that they also conform to the critical BSF design elements identified earlier.

Individual steel molds can be used to form many thousands of identical filter vessels. Wood molds can only produce twenty of thirty vessels before they need to be repaired or even replaced. The unit cost of vessels produced using steel molds is much smaller than that using wood molds.

At one time BSF's were manufactured using found plastic tanks that could easily be modified to form a BSF. Plastic garbage cans, empty plastic barrels that had been used for storing food and even new plastic containers were tried. The plastic container was fitted with a standpipe and diffuser (usually

some sort of plastic wash basin that fit the opening of the container). These were somewhat successful. However, the materials were often difficult to find, expensive and frequently resulted in changes in BSF design to try and use 'found' vessels that were too short or plastic wash basins that weren't quite the right size. There was very poor-quality control. The 'found' containers that were said to originally contain food stuffs actually had been used to hold chemicals toxic to humans. Many of the plastic garbage containers or similar types of containers that appeared suitable were manufactured from materials that are not considered food grade. 'Found' filter manufacturing was abandoned several years ago in favor of commercially manufactured plastic BSF's were not used at all.

Commercially manufactured plastic BSF's were quite expensive when manufactured in Canada; but, very affordable, even less expensive than concrete BSF's when manufactured in developing countries or manufactured in great quantities in developed countries.

Manufacture of filtering media is described in the aforementioned publications concerning media selection, preparation and installation.

Manufacture of diffusers and lids must conform to the criteria outlined in the description of the design of the BSF elements. Material is not important provided it is suitable for use with food and safe drinking water

#### Water Supplies Suitable for Treating

Water supplies used for the production of safe drinking water using the BSF or any other treatment technology should be as free from contaminants as possible. Water supplies that are known to be directly contaminated by wastes, liquid or solid, should be avoided. Even if the treatment technology used is performing at a very high efficiency, the quality of the treated water may still be unfit for human consumption.

The first steps in treating water for drinking is to ensure that the water supply is protected and the treatment has the best chance to produce high quality water. Simply taking water directly from a river, lake or a pond without use of infiltration wells (shallow, hand-dug, covered wells adjacent the surface water supply) is not advised. The infiltration wells will eliminate all of the large material and a great deal of the very small material providing a water supply that is much easier to treat with a minimum of filter cleaning. All groundwater wells should be covered and located such that water drains away from the well site itself. Water supplies, particularly wells, should be located as far as possible from latrines or possible contamination. Rainwater should be captured in covered barrels to avoid contamination from wind-blown debris and insects including mosquitoes. Springs should be developed and protected. Standpipes should be sturdily built and provided with adequate drainage. Human activity such as bathing and washing clothes should take place well away from the water supply. Animals should be prevented from contaminating a water supply by providing necessary water to them well away from the supply itself. Wastewater of any type should never be discharged into a water supply that is intended to be used to produce drinking water.

#### Measuring Bacteria Removal

The ability of a BSF to remove waterborne pathogens is typically determined by evaluating its ability to removal of certain 'indicator' bacteria that are present in the feces of warm blooded animals. The presence of these bacteria in a water supply 'indicate' that the water has come in contact with feces

and there is an unacceptable probability that the water will also contain pathogens the same warm-blooded animals (humans) may carry. The bacteria selected are Escherichia coli or e-coli bacteria and fecal coliform bacteria (in general). As well, total coliform bacteria are measured – coliform bacteria are present in the soil and the digestive systems of a great variety of other animals and the environment outside the bodies of any living organism. Total coliform bacteria measurements count the e-coli and fecal coliform bacteria as well. Fecal coliform counts include the e-coli bacteria and the two counts are often similar. If e-coli or fecal coliform bacteria are present the total coliform bacteria count can be expected to be ten times greater and never less.

Typical drinking water quality guidelines indicate that NO (zero) e-coli or fecal coliform bacteria may be present in water safe for drinking and very few total coliform bacteria may be present in water safe for drinking. The suggestion is that if ANY e-coli or fecal coliform bacteria are present the water is NOT safe for drinking. This is NOT necessarily valid when used to evaluate the suitability and safety of water treated by appropriately designed slow sand filtration and the BioSand Water Treatment technology. Traditional slow sand filters and BSF's will always remove 100% of parasites and when operated with a well developed biolayer can be expected to remove 90 to 99% of the bacteria and viruses. Pathogenic bacteria and viruses can be expected to be reduced to concentrations well below infectious levels.

A variety of quantitative and non-quantitative methods are available for evaluating the presence of indicator organisms in water. The cost of performing the specific tests, particularly the quantitative tests, can be quite high. Some evaluations are only suitable for a well funded research laboratory environment. The simplest evaluations and usually least expensive methods are misleading and almost useless.

The preferred quantitative method to evaluate the presence of bacteria (all types) is using a technique that uses an actual count. If the quantity of indicator bacteria in the untreated water is measured and compared with the quantity of indicator bacteria in the filtered water, the performance of the filtration can be determined as a per cent reduction. Exact procedures must be followed when taking the sample, transporting the sample and having the sample evaluated for the presence of bacteria.

Another quantitative method for evaluation of the presence of indicator organisms uses 'most probable' counts. This method is most useful for examination of wastewater that has unpredictable and very high concentrations of bacteria. The method is also very good to use in conjunction with the 'actual count' techniques to provide information on how the samples need to be tested. Generally, 'most probable' techniques do not provide as useful information as 'actual count' techniques when used to evaluate water that is used for drinking.

When the only information required is an indication of the presence (or absence) of indicator organisms, techniques suitably named, 'presence-absence' tests may be used. If the tests are positive one or more indicator organisms are present. This is the only information provided. 'Presence-absence' tests are of limited value in most of the environments and conditions where the BSF technology is used. However, if post-filtration disinfection is used and zero indicator organisms are expected, 'presence-absence' testing can be of great value.

## Performance

The household concrete BSF technology has been in use for more than 25 years (12 years in 2007). There are now estimated to be more than 2,000,000 in use. There have been numerous studies on a number of field projects and in laboratories in several reputable universities. Not all of the individuals or institutions executing the studies have a good understanding of the conditions in which the various household water treatment technologies must function. That said the BSF technology has performed quite satisfactorily.

Performance evaluation of any household water treatment technology is a technically sophisticated process. It must be performed in the context of the circumstances that the technology is used and must be performed by individuals who are very familiar with the technologies they are evaluating. No matter how carefully performance evaluations are designed and implemented, they will be seen wanting by someone. Ultimately, any water treatment technology must be considered useful and valuable by the people who use it – the consumer community. It is disturbing to observe how the performance evaluation process can be ruined and distorted by self-serving individuals and organizations in every corner of the world. Despite these concerns the **BioSand Water Filter technology has performed well.**

No other household water treatment technology can make all of the performance claims that the BSF technology can. That is because the BSF technology is based on well established, long accepted principles, that have been verified and demonstrated for almost 200 years and are understood and accepted by professionals in the water treatment industry. Water treatment professionals **expect** to see confirmation of the performance of the BSF technology in the circumstances in which it is used.

The following significant claims regarding the performance of an individual household BSF operating in the laboratory or field environment are:

1. Almost 100% removal of particulate matter larger than colloidal sized particles.
2. Almost 100% removal of colloidal sized particles if pretreatment is used.
3. 100% removal of parasites, helminthes and larger organisms.
4. 90% to 99% removal of bacteria and viruses.
5. Greater than 99% reduction in iron and manganese with or without pretreatment depending on characteristics of water.
6. Reduction in concentration of dissolved organic substances – will vary depending on the nature of organics and whether pretreatment is used.
7. Up to 50% removal of inorganic toxins, without use of pretreatment and when a biolayer has formed.
8. Up to 99% removal of inorganic toxins, including arsenic, mercury and lead, with use of pretreatment, with or without the formation of a biolayer.
9. Up to 99% removal of organic toxins with formation of biolayer.
10. Reduction of fluoride to concentrations safe for human consumption (under development using the Nalgonda technique from India).
11. Known to eliminate skin, eye, nose and other infections when used for bathing.
12. Capable of being appropriately operated and maintained with minimum or no supervision once consumers have been adequately trained.
13. Affordable.
14. Sustainable.

15. Desirable.
16. Operated with zero maintenance costs.
17. Life expectancy of ten years or more.

The following significant claims regarding the performance of BSF technology as used by entire communities around the world are:

1. Capable of being manufactured by target communities in every instance.
2. Capable of being technically supported by a great number of individuals and organizations worldwide.
3. Affordable by target communities.
4. Desirable by target communities.
5. Sustainable by target communities with minimal of product support.
6. Almost 100% acceptance and use by local consumers.
7. Significant improvement in the health of community – elimination of cholera, 40 to 60% reduction in diarrhea and associated gastro intestinal disease without use of any form of disinfection or other forms of water and sanitation intervention.
8. Support micro-business opportunities.

### Training

The household concrete BioSand Water Filter technology was developed to permit technology transfer at all levels of manufacturing and use. The first training programs were developed by 1995. Very good training programs and manuals were developed and implemented in the late 1990's and have improved significantly since. The training manuals and details pertaining to the design of the steel mold were only made available as part of week-long training programs.

There were many unusual challenges that the BioSand Water Filter training programs needed to overcome. The technology transfer needed to be as complete as possible. Individuals who took the training program needed to feel confident that they could implement household concrete BSF programs themselves. The training program needed to be accessible to individuals with little or no technical background – training used a minimum of technical jargon without compromising completeness of accuracy. The benefit of not using technical jargon was that the training was readily translated in the numerous circumstances where participants did not understand English. Training needed to be completed within five full working days and be affordable to participants. Training needed to be guided, as much as possible and practical, using color photographs (not black and white drawing or black and white photographs which lose or don't communicate considerable important information) demonstrating each step of the variety of activities being taught. The training identified additional resources that are available (internet) and be very useful to participants for little or no cost. Finally, after observing how the BSF technology was being compromised by well meaning but ill-informed implementing or training organizations I believed it was absolutely necessary to provide a technical resource that they could refer to or query when they had questions or when confirmation was required for some detail concerning the technology – the web site [www.manzwaterinfo.ca](http://www.manzwaterinfo.ca) was developed to serve this need.

Individuals who participate in BSF training programs with the intention to implement household concrete BSF programs or provide training to others are responsible for implementing their programs as described in the training they received and to train others in precisely the same manner as they were trained. There is little room for creativity. It has often been observed that a *major flaw of the BSF technology* is that it is *too simple!* It worries me that individuals can take a BSF training course or part of one and without ever implementing a program decide to make modifications to the technology. This is truly unfortunate! The designs and methodology provided are provided essentially without cost or royalty – the only price is that best efforts must be made to replicate the technology as described. It is understood that circumstances are different throughout the world and that strict adherence to the design and operating principles inherent to the BSF technology may be challenging. However, there have never been circumstances where modifications to design and implementation are justified. Worse, when changes were made, they inevitably compromised the integrity of the BSF technology itself and perhaps the use of the technology to help the many millions of people who could benefit from its use.

A situation that is both satisfying and disappointing is the ‘class project’ approach to sand filtration. The teacher demonstrates how a sand filter can be constructed with a clear plastic container and some fine sand that happens to be available. The demonstration is very useful if limited to teaching the nature of sand filtration and how a full-scale filter might work. Miniature concrete filters were actually used in the first projects in Nicaragua to describe to concrete filter design and operation to intended consumers, health workers and engineers. Occasionally, an overzealous teacher represents to the students that they have now created a ‘real’ sand filter that can be used to remove dangerous waterborne pathogens from their contaminated water supply in their home! The ‘mini’ sand filters the students create probably do about as good a job treating pathogen contaminated water as the sand-in-a-barrel filters discussed earlier. ‘Class projects’ of this nature should be limited to demonstration-type projects for which they are very useful. The manufacture of properly constructed sand filters is serious business.

### **Conclusions**

The concrete household BSF technology is about empowerment. It is empowerment of the individual, the consumers, the donors who provides the resources ‘to make a difference’ to the human condition. It is about empowerment of the implementing individuals operating independently or as a part of a larger organization often performing their tasks with minimal financial reward but with maximum personal satisfaction knowing how important their contribution to humanity is.

The concrete household BSF technology is mostly about helping individuals who benefit from the technology, while preserving their dignity, to improve their wellbeing and enabling them to realize their potential.

There are now a great many BSF designs that use exactly the same water treatment process based on exactly the same design principals described in this paper. The various types of BSF’s differ with respect to scale, construction material, appearance, cost, methods for managing the supply of untreated water to the filter and methods of maintenance. The various types do not compete with each other. There are applications for each of these types of BSF’s.

Many other types of household water filters have been developed and are being used. Many more will be developed. I think this is a good – who knows what kind of household water treatment technologies can be developed when the ingenuity of many, many talented and intelligent people put their minds to the problem.

**However, household water filters that are claimed to be BioSand Water Filters must conform in every respect to the design and operation principles described in this monograph.** This is particularly important in light of the health impact study recently completed on the use of household concrete BSF's in the Dominican Republic. This study did not confirm any other design or method of operation other than that presented.

There is no doubt that the BSF technology is 'making a difference' to the health of people worldwide.