Laboratory Comparison of The Peruvian Table Filter and The BioSand Filter

H2O-1B!: Clean Water for One Billion People

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Spring 2004

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1.0 Introduction

Each year, 3.4 million people worldwide – many of them children – die from water-, sanitation-, and hygiene-related diseases (WHO, 2000). Six thousand children die each day from diarrhea, which is often caused by fecal contamination of water sources. The majority of these children are under the age of five (WHO, 2000). Many of these people are undoubtedly among the 1.1 billion people who lack access to improved water sources. At the World Summit on Sustainable Development in September 2002, world leaders set a goal of halving the number of people without sustainable access to clean water by 2015.

The environmental track of the Masters of Engineering program in Civil and Environmental Engineering at MIT offers students a chance to become part of the solution to these water quality problems. During the past six years, students have had opportunities to work on a variety of water and sanitation projects in developing countries. These projects have included studies of solar disinfection in Nepal and Haiti, use of the BioSand filter in Nepal, use of the "Potters for Peace" filter in Nicaragua, and the design of wastewater lagoons in Brazil. This year two new countries were added to the list. During January of 2004, Brittany Coulbert traveled to Peru to study the Table Filter and Kori Donison went to the Dominican Republic to study BioSand filter use.

During the spring of 2004, Coulbert and Donison worked together on a study comparing thermotolerant coliform and turbidity removal efficiencies of the two types of filters. The study involved testing two versions of each filter. Table Filters were constructed using two different sizes of sand, while the BioSand filter was tested with and without a geotextile prefilter. The objective of this laboratory study was to answer the question: *Which filter(s) performs best in terms of turbidity and thermotolerant coliform removal?*

2.0 Background Information

2.1 The Table Filter

The Pan-American Center for Sanitary Engineering and Environmental Sciences (CEPIS) is a "Regional Center" of the Pan-American Health Organization (PAHO). PAHO serves as the Regional Office of the Americas for the World Health Organization (WHO), which is the United Nations specialized agency for health.

In June 2001, an earthquake measuring 7.9 on the Richter scale hit southern Peru, causing an immediate decline in the quality of surface waters. Many people living in rural Peru rely on surface waters (e.g. irrigation canals) for their drinking water supply. The surface waters in the southern Peruvian provinces of Arequipa and Tacna were of such poor quality after the earthquake that the government declared it an emergency situation. It called upon CEPIS and the country's Ministry of Health to deliver some form of water treatment to the families in these areas. In response to this request, 1,000 filters and 400 household chlorination systems were delivered to select families free of charge. Families were selected to receive a household treatment system based on their demographics. Preference was given to families with multiple children and/or elderly inhabitants, since children and the elderly are more likely to be negatively affected by contamination in their drinking water. This emergency relief effort was the result of the technical and financial support and cooperation of the Belgian organization DGCI, CEPIS, and the Peruvian Ministry of Health.

CEPIS developed a sand-and-candle filter, which it named the *Filtro de Mesa* or "Table Filter." CEPIS combined the technologies of slow sand filtration and ceramic candle filtration in an attempt to improve upon the respective techniques. CEPIS' Table Filter design includes sand to act as a pre-filter to prevent two Pozzani ceramic candle filters[1] from quickly becoming clogged by the highly turbid water found in the user communities in Peru. The combination of sand and ceramic filtration allows the filter to have a flow rate faster than those typically seen in filters with ceramic candles alone. This design also decreases the need for frequent filter maintenance due to clogging. The third component of CEPIS' design is a non-woven polypropylene geotextile cloth manufactured in Peru, which acts as a roughing filter. This pre-filter prevents the sand from becoming clogged too quickly with organic material present in the extremely turbid water. Figure 1 shows a labeled cross-section of the upper bucket of a Table Filter.

[1] Ceramic filters are made of kiln-fired clay containing micro-pores and treat water by straining out organic particles as water flows through the pores (Dies, 2003). "Candle" refers to the cylindrical shape of a certain type of ceramic filter. These cylinders are hollow on the inside, which allows water to filter through the outside walls of the cylinder (which is closed on top) and drain out through the bottom. The candle filters used in the Table Filter in Peru, and brought to MIT for testing, are made by Pozzani (www.pozzani.co.uk) and are imported from Brazil.

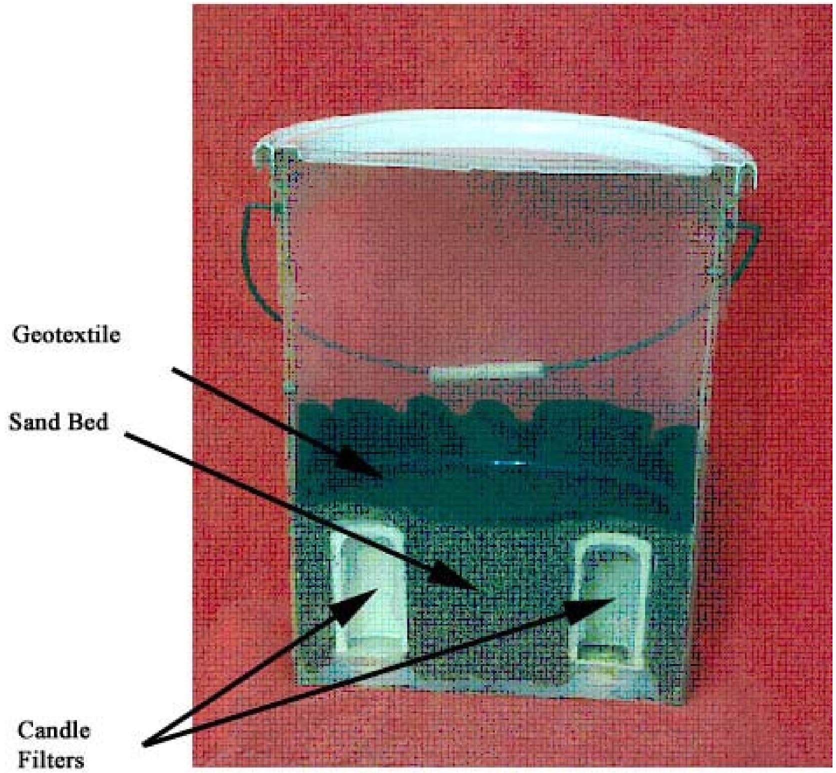

Figure 1: **Cross Section of CEPIS' Table Filter. Source: CEPIS.**

2.2 The BioSand Filter

The BioSand filter was developed in the early 1990s by Dr. David Manz while he was working as a civil engineer at the University of Calgary. Dr. Manz's BioSand filter is a low cost (approximately $35 US) household-scale slow sand filter. BioSand filters were first used for water treatment in 1993, when one was installed in each home in Valler de Menier, Nicaragua. The efficacy of the filter was clearly demonstrated in 1996, when a doctor working for the NGO "Samaritan's Purse" reported that no one in Valler de Menier contracted cholera while many people in other portions of the country died from the disease. Recognizing the BioSand's potential for success as a simple and sustainable household water treatment technology, Samaritan's Purse has since installed 26,000 BioSand filters worldwide. At the end of 2001, various church groups and NGOs, including Samaritan's Purse, had installed more than 50,000 BioSand filters in more than 40 countries worldwide, including Haiti, the Dominican Republic, Nepal, and Nicaragua (CAWST, 2003). The BioSand filter was introduced to the Dominican Republic in 2000.

The BioSand filter consists of a plastic or concrete shell containing a layer of sand above two layers of gravel. Water is poured into the headspace of the filter and flows through a plastic or wooden diffuser plate. This diffuser plate has holes of 0.125 inches-diameter two inches apart in a uniform grid. The diffuser plate spreads the water over the surface of the sand filter bed evenly, minimizing disturbance of the delicate layer of biological activity directly above the sand bed, known as the *schmutzdecke*. Water passes through the filter bed as particle straining removes the majority of the bacteria and turbidity. After passing through the sand bed, water passes through a layer of small gravel and a layer of large gravel, each preventing sand and gravel particles from the above layers from entering the filtered water. Finally, water flows from the large gravel layer and through the exit tube of the filter. All sand sizes and layer thicknesses for both the BioSand filter and the Table Filter are given in the methods portion of this paper. Figure 2 is a labeled cross section of the BioSand filter.

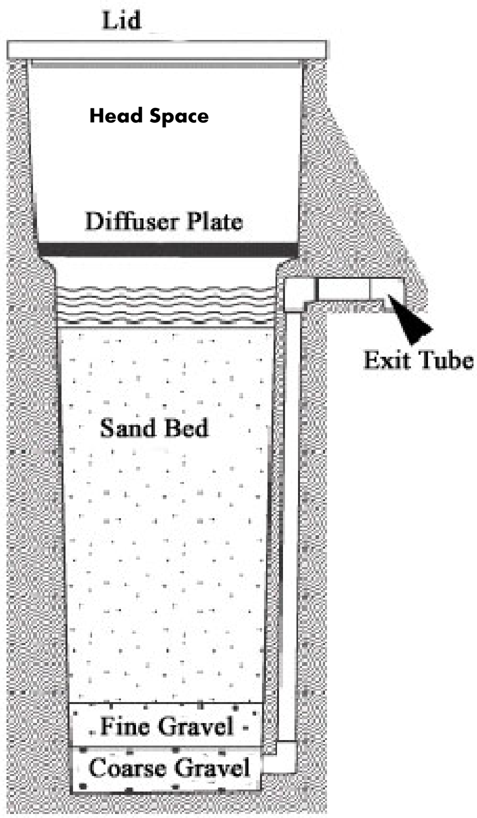

Figure 2: **Cross Section of a BioSand Filter. Source: www.friendswhocare.ca/FWCpage2A.htm**

3.0 Methods

3.1 Table Filter Construction

Two Table Filters were constructed in the lab at MIT. Materials for the construction of these two filters included four 20-liter buckets with lids, four Pozzani ceramic candle filters[2], two pieces of non-woven polypropylene geotextile[3], plastic tubing[4], sand, and two plastic spigots. With the exception of the sand, all materials were purchased in Peru. First, two sets of matching holes were punched (using a heated copper pipe) into each of the lids of the two 20-liter buckets designated as the "bottom buckets" and in the bottom of the two buckets designated as the "top buckets." Through the use of plastic wing nuts and rubber washers, the candles, top bucket, and bottom bucket's lid are attached together, forming a water-tight seal so that all water from the top bucket will flow into the lower bucket through the ceramic candles.

Next, two different grades of sand were prepared, one for each of the two filters that were tested. The "fine sand" was prepared to the specifications given in the construction manual from Peru. The "medium sand" was the same as that used in the BioSand filter.

For the filter designated "Fine Sand," a mix of fine play sand and commercially-available medium-grade sand was filtered through an ASTM #20 Mesh[5] sieve into an ASTM #60 Mesh[6] sieve (this mix of sand was intended to mimic the sand available in Peru). Sand retained in the ASTM Mesh #60 mesh was washed with tap water (which contained chlorine). The washing process consisted of placing a few inches of sand in a 20-liter bucket and filling the bucket with tap water several inches higher than the level of the sand. The water and sand were swirled around by hand for about a minute to encourage any fines or floating particles to become suspended in the water, which was then decanted. This process was followed five times for each small amount of sand until all the sand needed for the filter had been rinsed by hand five times.

For the filter designated "Medium Sand," the commercially available medium-grade sand was filtered through a piece of mosquito netting[7]. The sand that passed through the netting was retained and washed using the process described above. The cleaned sand was added to each filter until it was approximately five centimeters above the tops of the candle filters. This extra layer of sand creates a buffer, as users periodically lose some of the sand while cleaning their filter. As the final step in the construction of the upper bucket, the geotextile cloth is cut into a circle of 35cm-diameter before being placed on top of the sand. An 84cm plastic tube that is shaped into a ring secures it in place.

Finally, a plastic spigot is inserted in the bottom bucket just far enough off the bottom so as to allow the filter to be set flush on a tabletop. Construction was completed by stacking the filter

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[2] The Pozzani ceramic candle filters are 9.5cm tall and 5.5cm in diameter.
[3] The geotextile is 2.0-2.5mm thick and has a permeability of 0.4-0.6cm/s with pores between 0.15 and 0.2mm.
[4] Each filter requires 84cm of hollow plastic tubing that is 3/8-inch in diameter and 2cm of 5/16inch-diameter tubing to connect the ends of the larger tube so that it forms a circle.
[5] ASTM Mesh #20 corresponds to a mesh size of approximately 0.85-mm, BS Mesh #18, and Tyler Mesh #20.
[6] ASTM Mesh #60 corresponds to a mesh size of approximately 0.25-mm, BS Mesh #60, and Tyler Mesh #60.
[7] The pores of the mosquito netting are approximately 1-mm wide. A 1-mm pore size corresponds to ASTM Mesh #18, BS Mesh #16, and Tyler Mesh #16.

assembly on top of the water collection bucket with the spigot (DGCI, 2003).[8] As an additional cleaning step, several liters of water were run through the completed filters before testing began.

Figure 3: **Table Filter Setup During Laboratory Experimentation.**

3.2 BioSand Filter Construction

First, sand from previous experiments was removed from two plastic Davnor BioSand filters. These filters were cleaned with sterile water and allowed to dry. Three types of media were used in the filter: medium sand, small gravel, and large gravel. Medium sand used in BioSand filter construction was the same sand used in the construction of the Table Filter, and the same sieving and rinsing procedures were used. Small gravel[9] and large gravel[10] were also rinsed with tap water.

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[8] All of these instructions and specifications are taken from a Table Filter user's manual, distributed by CEPIS and the Ministry of Health in Peru.
[9] The small gravel is between 1 and 2-mm in diameter. A 1-mm pore size corresponds to ASTM Mesh #18, BS Mesh #16, and Tyler Mesh #16. A 2-mm pore size corresponds to ASTM Mesh #10, BS Mesh #8, and Tyler Mesh #9.
[10] The large gravel is between 5 and 6-mm in diameter. A 5-mm pore size roughly corresponds to ASTM Mesh #4, BS Mesh #3.5, and Tyler Mesh #4.

After adding several inches of water, large gravel was added to the bottom of the filters[11] until it reached the blue line shown on the side of the filter in Figure 4 (located five centimeters from the bottom of the filter). After the addition of more water, small gravel was added on top of the leveled gravel. This small gravel was leveled until it reached the orange tape on the outside of the filter (located 10 cm from the bottom of the filter), and the process was repeated with the medium sand. This sand was added to the filter until it reached the yellow tape (56 cm from the bottom of the filter) on the side of the filter shown in Figure 4.

Figure 4: **BioSand filter Setup During Laboratory Experimentation.**

3.3 Sample Collection

The "source water" fed to the Table Filters and BioSand filters in the MIT Building 1 water lab during this laboratory study was meant to imitate the highly contaminated waters that the authors discovered being fed into similar filters at their respective January 2004 field sites of Peru and the Dominican Republic. In order to create a similar level of contamination in the water, the authors mixed nine parts river water with one part municipal sewage water (a 1:10 dilution). Charles River water was obtained from a site near the Harvard Bridge (located at the intersection of Massachusetts Avenue and Memorial Drive in Cambridge, MA). A 20-liter plastic bucket on a rope was lowered to collect water. This water was brought back to the laboratory and used to

[11] Sand and gravel were always added to water and never vice versa.

create a 1:10 dilution of municipal sewage water obtained from the South Essex Sewerage District wastewater treatment plant in Salem, MA by Susan Murcott. Two liters of sewage water was added to a bucket containing 18 liters of Charles River water. The waters were mixed with a large plastic spoon and allowed to warm to room temperature for filtration and analysis the following day.

Source water samples were obtained after stirring the sewage water / Charles River water mix prepared the previous day. A clean plastic beaker rinsed in tap water was dipped into the mix to collect a sample and set aside for analysis. Pause water samples were each obtained by carefully dipping a clean plastic beaker into the BioSand filter's head space, making sure not to disturb the biofilm developing at the sand-water interface. Filtered water samples were obtained directly from the spigot of the Table Filter or the spout of the BioSand filter and were collected in a previously heat-sterilized glass beaker.

In the case of the Table Filter, water dripped down from the candle filters into the receiving bucket before it flowed out the spigot. Because the hole for the spigot is raised approximately 4 cm from the bottom of the receiving bucket, the filtered water does not completely drain out. Each day of testing before the source water was added to the top of the Table Filter, the spigot was opened and excess water was allowed to drain out. One to two liters of water that sat below the spigot level were left in the receiving bucket so as to mimic the practices witnessed in Peru. This meant that the freshly filtered water was able to mix with the previously filtered water before each filtered sample was collected.

Five liters of the same source water mix were added to each filter every day for the duration of the spring lab tests. This semi-continual feeding was designed to mimic the daily use of a filter in Peru or the Dominican Republic. It also helped ensure that the biofilm layer in the BioSand filter was fed regularly. Coulbert and Donison worked together in the laboratory, each testing their own two filters but using exactly the same source water. On most days, tests were performed simultaneously, however on a few days, only one type of filter was tested, which explains the slight difference in average source water measurements reported by the two researchers.

3.4 Membrane Filtration

The membrane filtration procedure used during spring 2004 followed Standard Method #9222 from *Standard Methods for the Examination of Water and Wastewater (20th Edition)*. A desired volume of sample was poured from a beaker or flask into a pre-sterilized Millipore stainless steel filter holder containing a 0.47 µm pore-size paper filter. If the desired volume was less than 1-ml (or in some cases, less than 100-ml), dilutions were performed whereby a portion of the sample was pipetted into a volume of distilled water (obtained from another MIT Civil Engineering laboratory) to result in the appropriate dilution which would allow the desired volume of sample to be filtered. After filtration, the filter paper was placed in a disposable, sterile plastic petri dish on an absorbent pad onto which had been poured one ampoule of m-FC broth, which selects for thermotolerant coliform. The petri dishes containing the filter and the broth were inverted and placed in a portable single-chamber Millipore incubator at 44.5ºC for 24 hours.

After incubation, the petri dishes were removed and bacterial colonies were counted. The desired number of colonies per plate is between 20 and 60 colonies for m-FC broth. Counts between 20 and 200 were considered valid data, as there is a range between the upper limit of statistical significance in a 1:100 dilution, for example, and the lower limit of detection on a 1:10 dilution.

Duplicates and blanks were completed on each day of laboratory testing. Duplicates were completed at random to verify thermotolerant coliform counts in a given sample. Blanks were completed with the water used for diluting the samples. Completing blanks allowed the team to verify both the lack of thermotolerant coliform contamination of water used for dilutions and the complete sterilization of the membrane filtration devices.

3.5 Sterilization

Sterilization of equipment was necessary to ensure that bacterial counts reflected only the bacteria from a given sample and not from contamination, such as from the water used to rinse the equipment, water from previous samples, or contamination from the environment.

Glass graduated cylinders, flasks, and beakers were sterilized in an oven set at 170ºC for one hour. Once removed from the oven, glassware that was not needed for immediate use was capped with aluminum foil rinsed in isopropanol to guard against subsequent contamination.

Following the sterilization procedure outlined by Millipore, the membrane filtration assembly was sterilized by soaking a rope wick on the base of the device with methanol. The methanol was lit with a cigarette lighter. The vessel used to collect the water during filtration was placed over the filter assembly for 10 to 15 minutes, creating an air-tight seal, which allowed a formaldehyde byproduct of the ignited methanol to sterilize the inside of the filter assembly.

3.6 Turbidity Measurement

Turbidity is a measurement of the amount of particles floating in the water, or its “cloudiness.” Turbidity of water samples was determined by placing a 10-ml aliquot of water in a sample cell. The sample cell was placed in a Hach 2100P Turbidimeter™, which measures the amount of light that scatters at a 90-degree angle when passed through the water sample. The reading was recorded and the process was repeated at least once more for accuracy. These readings, expressed in terms of the Nephelometric Turbidity Unit (NTU), the U.S. EPA-designated unit of turbidity measurement, were recorded and averaged for each water sample. Turbidity was measured in the water both before and after filtration. Prior to all lab work, the turbidimeter was standardized using Formazin standards following the procedure outlined in the user manual that accompanies the Hach turbidimeter kit.

3.7 Bacterial Disposal

After the bacterial plates had been counted, a 1:10 dilution of household bleach and water was applied to each plate. Once the bacteria had been killed in this way, the plates were thrown away.

4.0 Results

4.1 Table Filter Turbidity Removal

Between February 17 and March 19, 2004, several sets of analysis were performed on source water and filtered water samples from the two Table Filters to test for both turbidity and TTC.

The average turbidity of the source water that was used on the days the Table Filters were tested was 8.1 NTU. Filtered water samples from the Medium Sand Filter had an average turbidity of 0.5 NTU, and those from the Fine Sand Filter had an average turbidity of 0.6 NTU. A summary of the turbidity values of the water samples is presented numerically in Table 1 and graphically in Figure 5. The average percent removal of turbidity was 94% for the Medium Sand Filter and 93% for the Fine Sand Filter.

Table 1: **Table Filter Turbidity Removal.**

Date	**Turbidity: Source Water (NTU)**	**Turbidity: Medium Sand Filter (NTU)**	**Turbidity: Fine Sand Filter (NTU)**	**Turbidity % Removal: Medium Sand Filter**	**Turbidity % Removal: Fine Sand Filter**
February 17	4.60	0.30	0.00	94%	100%
February 20	4.24	0.88	0.54	79%	87%
February 23	6.03	0.94	0.85	84%	86%
February 27	15.60	0.76	0.94	95%	94%
March 1	4.40	0.64	0.76	86%	83%
March 5	8.33	0.45	0.60	95%	93%
March 8		0.30	0.59		
March 12	14.77	0.21	0.59	99%	96%
March 15	6.60	0.30	0.50	96%	92%
March 19	8.63				
Average	**8.13**	**0.53**	**0.60**	**94%**	**93%**

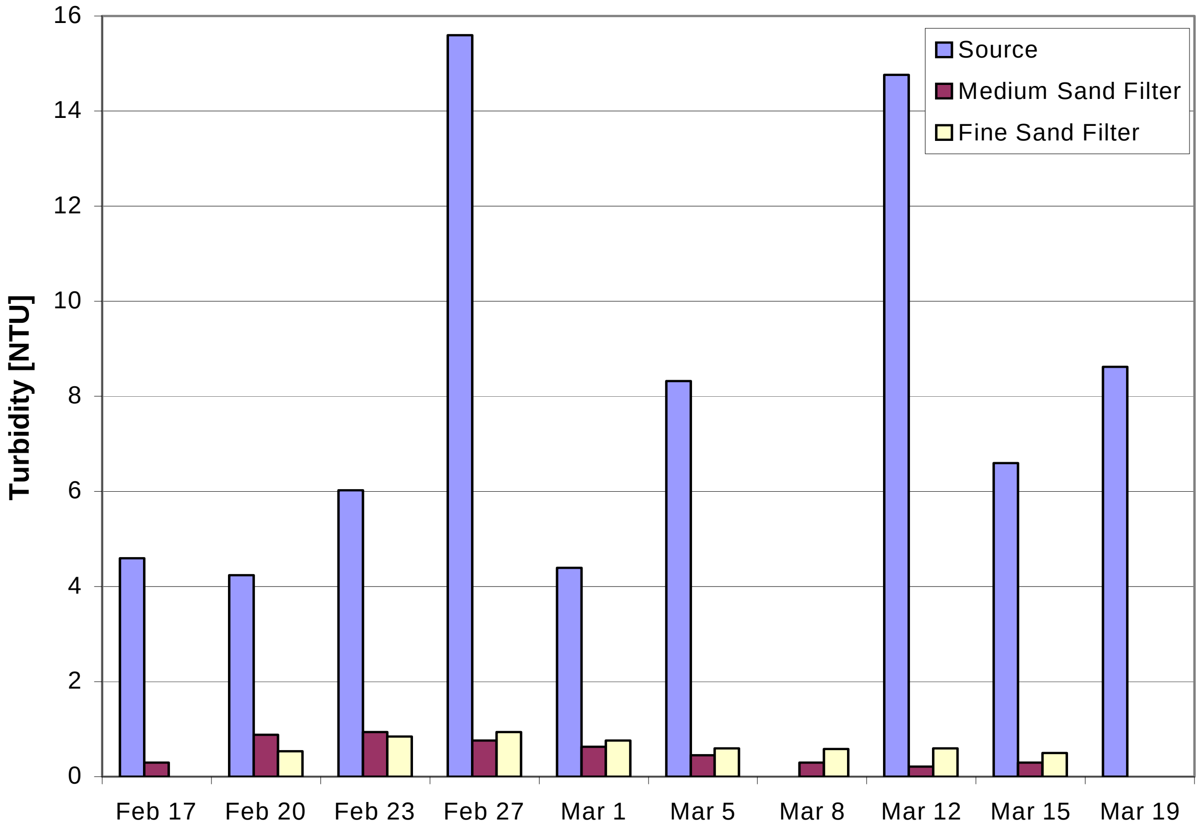

Figure 5: **Turbidity Concentrations in Source and Table Filter Water. MIT, Spring 2004.**

4.2 Table Filter Thermotolerant Coliform Removal

As shown in Table 2, the average concentration of thermotolerant coliform (TTC) in the source water was 16,152 TTC CFU/100ml[12], ranging from a low of 1,400 TTC CFU/100ml to a high of 46,000 TTC CFU/100ml. The Medium Sand Filter reduced this amount to an average of 76 CFU TTC/100ml, with individual values ranging from 5 to 205 TTC CFU/100ml. The Fine Sand Filter reduced the levels of thermotolerant coliform to an average of 469 TTC CFU/100ml, with actual values ranging from 70 to 1,340 TTC CFU/100ml. The Medium Sand Filter removed an average of 98% of thermotolerant coliform, while the Fine Sand Filter removed 97%. Table 2 gives a summary of the thermotolerant coliform data from each day of testing that gave valid results (i.e. results that fell in the ideal 20-60 CFU range or in the acceptable 1-200 CFU range as per Standard Method #9222). Figure 6 shows the thermotolerant coliform percent removals of each filter.

[12] Results for thermotolerant coliform concentration are reported as "colony-forming units" (CFU) per 100ml.

Table 2: Table **Filter Thermotolerant Coliform (TTC) Removal.**

Date	TTC: Source Water (CFU TTC/100 ml)	TTC: Medium Sand Filter (CFU TTC/100 ml)	TTC: Fine Sand Filter (CFU TTC/100 ml)	TTC % Removal: Medium Sand Filter	TTC % Removal: Fine Sand Filter
February 20	1,400	185	75	89%	95%
February 23		205			
March 1	12,000	8	70	99%	99%
March 5	4,600	56		99%	
March 8	46,000	61	1,340	99%	97%
March 12	7,000	12	300	99%	96%
March 15	38,000		835		98%
March 19	4,067	5	195	99%	95%
Average	**16,152**	**76**	**469**	**98%**	**97%**

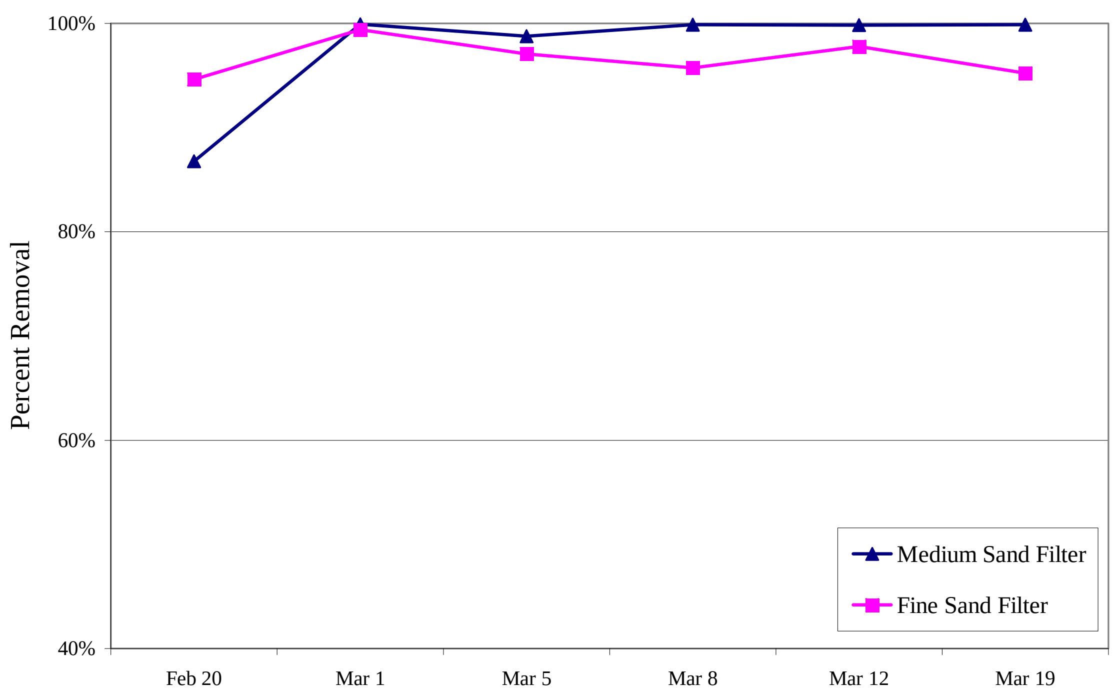

Figure 6: **Comparison of Percent Removal of TTC by Medium & Fine Sand Table Filters. MIT, Spring 2004.**

4.3 BioSand Filter Turbidity Removal

Between February 20 and March 19, 2004, seven sets of thermotolerant coliform and turbidity measurements were taken for the two BioSand filters. The average source water turbidity was 8.2 NTU. Both BioSand filters, with and without the geotextile, output water with an average of

0.6 NTU. Table 3 and Figure 7 show turbidity concentrations in the source water and in the treated water of the two filters. Percent removal of turbidity ranged from 88% and 96% for the BioSand filter with the geotextile prefilter, and from 87% to 94% in the BioSand filter with the geotextile. Average percent removal of turbidity was 92% in both BioSand filters.

Table 3: **BioSand Filter Turbidity Removal.**

Date	**Turbidity: Source Water (NTU)**	**Turbidity: Geotextile BioSand Filter (NTU)**	**Turbidity: Non-Geotextile BioSand Filter (NTU)**	**Turbidity % Removal: Geotextile BioSand Filter**	**Turbidity % Removal: Non-Geotextile BioSand Filter**
March 1	5.9	0.7	0.8	88%	87%
March 5	6.1	0.7	0.5	89%	92%
March 7	7.1	0.6	0.5	92%	93%
March 9	7.6	0.7	0.5	90%	93%
March 12	13.8	0.5	0.7	96%	94%
March 15	8.2	0.7	0.5	91%	94%
March 19	8.6	0.6	0.6	93%	93%
Average	**8.2**	**0.6**	**0.6**	**92%**	**92%**

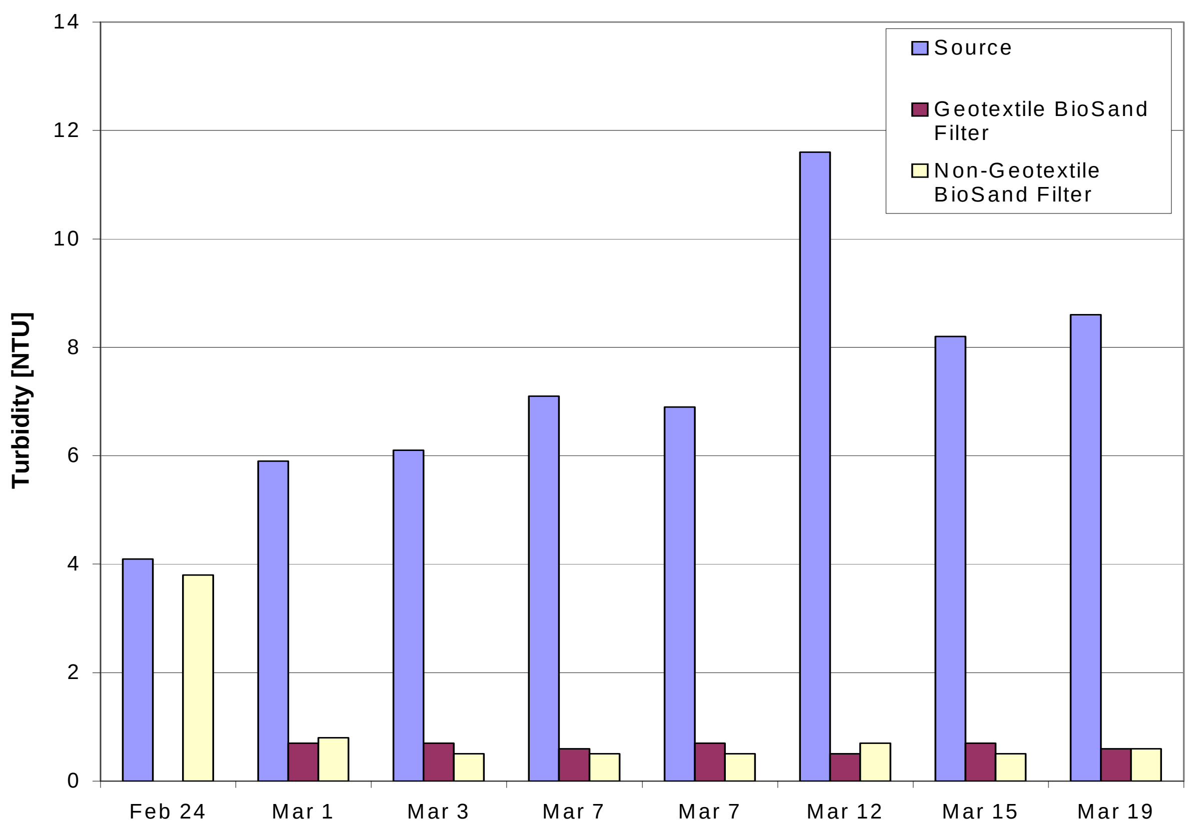

Figure 7: **Turbidity Concentrations in Source and BioSand-Filtered Water. MIT, Spring 2004.**

4.4 BioSand Filter Thermotolerant Coliform Removal

Source water contained an average concentration of 22,300 TTC CFU/100 ml, and actual concentrations ranged from 1,400 to 46,000 TTC CFU/100 ml. In the spring 2004 laboratory study, thermotolerant coliform concentrations were always lower in water filtered with the BioSand filter than in the source water. This was in contrast to several negative percent removal results (i.e. contamination increased with the use of the filters) obtained with the BioSand filter in the Dominican Republic, probably due to the use of chlorinated water as influent with those several BioSand filters. In the lab, filtered water from the BioSand filter *without* the geotextile contained an average of 970 TTC CFU/100 ml, and concentrations ranged from 150 to 2,125 TTC CFU/100 ml. Filtered water from the BioSand filter *with* the geotextile prefilter averaged 5,410 TTC CFU/100 ml with a range from 80 to 14,300 TTC CFU/100 ml. Unlike the two Table Filters, which performed similarly in terms of TTC removal, there was a clear difference between TTC removals of the two BioSand filters. The BioSand filter without the geotextile removed an average of 90% of source water TTC while the BioSand filter with the geotextile removed an average of 80%. Concentrations of TTC in source water and filtered water from both BioSand filters are shown in Table 4, and percent removals of TTC for both filters are shown in Figure 8.

Table 4: **BioSand Filter Thermotolerant Coliform (TTC) Removal.**

Date	**TTC: Source Water (TTC CFU/ 100 ml)**	**TTC: Geotextile BioSand Filter (TTC CFU/ 100 ml)**	**TTC: Non-Geotextile BioSand Filter (TTC CFU/100 ml)**	**TTC % Removal: Geotextile BioSand Filter**	**TTC % Removal: Non-Geotextile BioSand Filter**
2/20/2004	1,400	140	670	90%	52%
2/24/2004	10,000	80	310	99%	97%
3/7/2004	18,000	3,600	510	80%	97%
3/8/2004	46,000	14,300	1,400	69%	97%
3/9/2004	40,000	11,000	2,125	73%	95%
3/15/2004	38,000	8,000	1,600	79%	96%
3/19/2004	2,700	800	150	70%	94%
Average	**22,300**	**5,410**	**970**	**80%**	**90%**

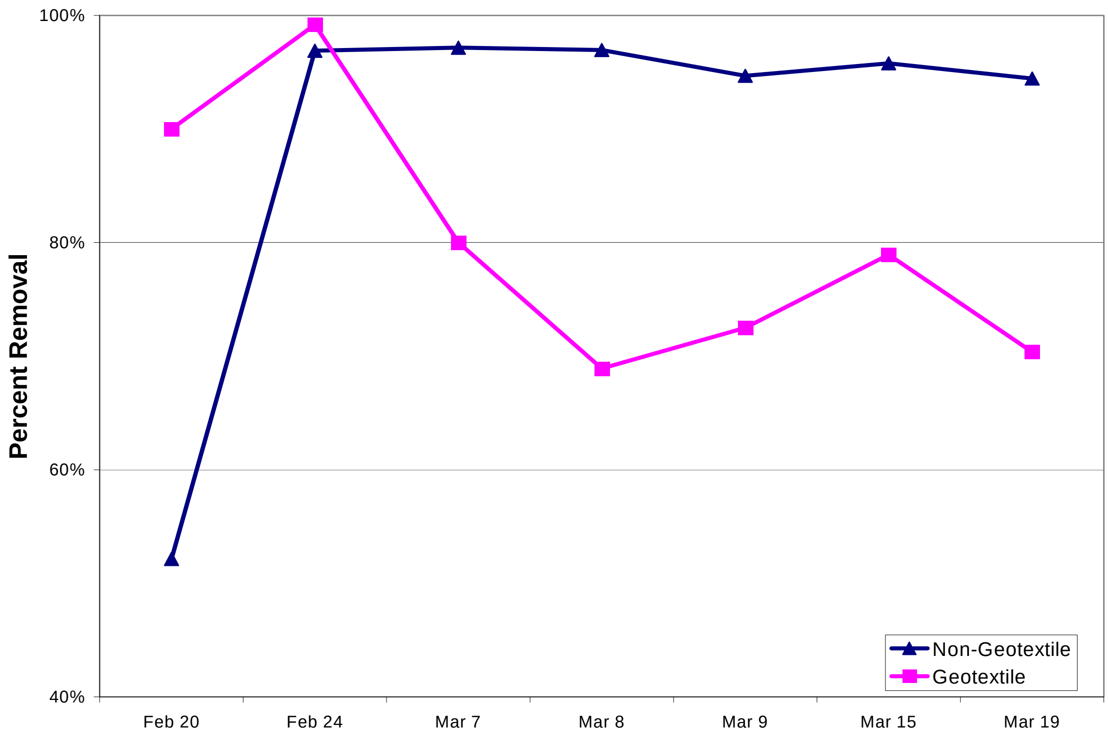

Figure 8: **Comparison of Percent Removal of TTC by a BioSand Filter with and without a Geotextile Prefilter. MIT, Spring 2004.**

5.0 Discussion, Conclusions, and Recommendations

5.1 Table Filter

The Peruvian Table Filters performed well in laboratory experiments. The Medium and Fine Sand Filters performed comparably in terms of turbidity removal, as they reduced the level of turbidity in water from 8.1 to 0.5 and 0.6 NTU respectively. These low levels of turbidity are relatively close to the laboratory's tap water reading of 0.2 NTU and well below the WHO turbidity guideline of less than 5.0 NTU for drinking water (WHO, 1997).

The Medium and Fine Sand Table Filters removed an average of 98% and 97% of thermotolerant coliform contamination respectively. While this *is* a significant percentage of thermotolerant coliform, the filtered water still does not meet the WHO standard of *less than 1* TTC CFU/100ml (WHO, 1997). This means that the Table Filter design still has room for improvement if the goal is to meet WHO microbial guidelines.

Over the length of the experiment, the Medium Sand Filter usually removed thermotolerant coliform better than the Fine Sand Filter. The average concentration of TTC in water from the Medium Sand Filter was 76 TTC CFU/100ml compared to 469 TTC CFU/100ml in water from the Fine Sand Filter. This limited laboratory study indicates that the Medium Sand Filter design may remove thermotolerant coliform more effectively than that of the Fine Sand Filter.

During the summer of 2004, additional laboratory tests at MIT on the two Table Filters will be carried out in order to try to confirm this result. The Medium and Fine Sand Table Filters will also be tested for TTC removal *without sand* to try to discover whether variations in the ceramic candles may be affecting the difference in TTC removal seen between the two filter designs. The four Pozzani candles (a set of two is used in each filter) should in theory be the same, but if the removal rates vary between the two filters after the sand has been removed, then it cannot be accurately concluded that the difference in sand size caused the difference in treatment levels of the two filters, and it may be that the difference is caused by improper quality control in the manufacturing of the Pozzani candle filters.

5.2 BioSand Filter

The laboratory study revealed that the BioSand filter is capable of consistently removing a significant amount of turbidity and thermotolerant coliform contamination over an extended period of time. Both BioSand filters reduced the source water's turbidity from an average of 8.2 NTU down to 0.6 NTU, which far surpasses the WHO turbidity guideline of less than 5 NTU for drinking water.

The BioSand filter used with a geotextile removed an average of 80% TTC while the BioSand filter without a geotextile removed 90% TTC. When used without a geotextile prefilter, the BioSand filter's thermotolerant coliform removal efficiency improved over time (see Figure 8), confirming that the period of filter ripening is important to bacterial removal efficiency. Also, although the sand was washed thoroughly before filter construction, it may be that some contamination was contained in the sand and washed out during the first several "uses" of the filter.

The use of a geotextile prefilter did not aid in thermotolerant coliform removal. Removal efficiency dropped steadily as the experiment progressed, as illustrated in Figure 8. Since source water for the two filters was identical, the geotextile prefilter may have either provided a medium that contributed to contamination or retained some chemical or microbial constituents critical to thermotolerant coliform removal. While the BioSand filters, especially the version without a geotextile, removed a large amount of TTC, the filtered water was still far from meeting the WHO guideline of less than 1 TTC CFU/100ml. The BioSand filters with and without a geotextile prefilter produced an effluent with an average of 5,410 TTC CFU/100ml and 970 TTC CFU/100ml respectively, both of which are orders of magnitude above "less than one."

5.3 Table Filter vs. BioSand Filter

The results of the two Table Filters and two BioSand filters that were tested in the laboratory at MIT during spring 2004 are compared in Table 5. Although the two Table Filters and the two BioSand filters removed approximately the same percentage of turbidity, the Table Filter removed a higher percentage of TTC on average. Because the BioSand filter is typically used without a geotextile cloth, it is appropriate to compare the "Non-Geotextile" version to the Table Filters. The average TTC removal rate for the BioSand Filter without geotextile is 90%, but the data in Table 4 indicates that one day of 52% removal significantly affected this average. If this low removal rate is attributed to the growth time necessary for the *schmutzdecke* to form, the average TTC removal moves to 96%, which is very close to the Table Filter's 97%. (Recall that the Table Filter with fine sand most closely replicates the filters in Peru.) Since laboratory tests were performed only for a limited time, more tests would need to be performed on the filters to draw any solid conclusions about their relative performance, although the preliminary data indicates that the Peruvian Table Filter may treat water comparably in terms of turbidity removal and as effectively or perhaps more effectively than the BioSand filter in terms of TTC removal.

Table 5: **Comparison of Percent Removal Averages of the Four Filters.**

	Turbidity Removal	**TT Coliform Removal**
Table Filter: Medium Sand	94%	98%
Table Filter: Fine Sand	93%	97%
BioSand Filter: Non-Geotextile	92%	90%
BioSand Filter: Geotextile	92%	80%

The answer to our research question is that the Medium Sand Table Filter performed best in the removal of turbidity and TTC. If we had to choose one of the four filters to begin drinking from immediately, that is the one we would choose. But the truth is that the lab tests shed more light than that on the abilities of the filters. The TTC removal rates of both Table Filters are higher than those of the BioSand filters. This implies that addition of ceramic candles to sand filters helps increase their efficacy in TTC removal. Future research could help to further explore the effects of combining ceramic and sand filtration techniques.

Ultimately, the data presented in this report shows that all four filters remove a more than adequate amount of turbidity and neither of them remove enough TTC. This means that both the Table and BioSand filters could use further research and experimentation to improve upon their TTC removal capabilities.

6.0 Works Cited

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