Melanie Pincus
BioSand Pitcher Filter

Project Summary

Access to safe water remains an urgent human need in many countries. Tremendous human suffering is caused by diseases that are largely conquered when adequate water supply and sewerage systems are installed. The need for a simple, inexpensive and effective water treatment technology is great. This proposal is for funding for the development of a new household water filter that costs less than $1 USD – the BioSand pitcher filter. Developed specifically for use by poor people in developing countries, this technology has much to offer as a purveyor of safe household drinking water. System strengths include simplicity, effectiveness, economic sustainability, social acceptability, and reliance on local resources. The author plans to work in collaboration with Bhikku Maitri, the head of the International Buddhist Society in Lumbini, Nepal (a Buddhist center and local health clinic), to implement a pitcher filter pilot project in the region.

The BioSand pitcher filter was conceptualized during January 2003 field investigations in rural Nepal in response to observed drawbacks of recently installed concrete BioSand filters (slightly modified versions of plastic household water filters manufactured by Davnor Water Treatment Technologies, Ltd., in Calgary, Albert, Canada):

- Though the Davnor BioSand filter is meant to provide water for all types of domestic activities, filter owners reported using filtered water for drinking only, or drinking and cooking. No one used filtered water for bathing or washing laundry.

- The ideal flow rate of the Davnor BioSand filter is 20-30 L/hr. Of the nine functioning filters evaluated in the Lumbini, Nepal survey, five had flow rates less than 6 L/hr, and four of those five had flow rates less than 3 L/hr.

- Concrete BioSand filters are currently a relatively expensive technology for poor rural communities; filter cost is estimated at 2000 Nepali Rupees or $27 USD (Maitri, 2003). This is simply too expensive for rural villagers whose annual income is less than $250 USD.

- Concrete BioSand filters are extremely heavy and cumbersome.

- The BioSand filter technology appears to be well-liked by users in Lumbini district communities. Many individuals expressed an interest in aquiring a filter.

A BioSand pitcher filter incorporates the following positive points if proved a viable water purification technology:

- The pitcher filter is designed to provide safe drinking water at the household level, and may compete in a water supply market with concrete BioSand filters used for drinking water purification.

- Flow rates of BioSand pitcher filters are comparable to (and in some cases exceed) flow rates of concrete BioSand filters currently in the field.

- The pitcher filter is cheap. Materials for prototype construction cost less than 80 Nepali Rupees (approximately $1 USD) per filter. This price tag is 25 times less than that of the concrete version.

- The pitcher filter is light and easily manageable.

The BioSand filtration technology is already well accepted by many communities and filter users are relatively comfortable with operating protocol. Many of the same principles of construction, operation and maintenance for concrete BioSand filters apply to pitcher filters. This facilitates pitcher filter introduction, as technical knowledge to be transferred will be minimal.

In January of 2003, the author constructed two pitcher filter prototypes using locally obtained materials and preliminary testing was performed. Subsequent laboratory experiments at MIT in March and April were also conducted. The purpose of these investigations was to conduct a preliminary evaluation of pitcher filter viability by cross-checking their performance with the concurrent performance of Davnor concrete and plastic BioSand filters.

In general, results from field and laboratory experiments on BioSand pitcher filters are very encouraging and suggest the viability of pitcher filters as a household water purification system. Microbial removal performance of pitcher filters are comparable to, and sometimes exceed, performance of the concrete and plastic BioSand filters. Funding from the IDEAS organization will facilitate additional laboratory and field testing to optimize the bioremediation effectiveness of the pitcher filter technology.

BioSand Pitcher Filters

BioSand Pitcher Filter Overview

Particle Removal Mechanisms

The BioSand pitcher filter relies on natural biological, chemical and physical processes to purify raw water. A 5 cm layer of standing water supports a microbial community at the surface of the sand layer; this diverse ecosystem consists of algae, bacteria, protozoa, and small invertebrates, which are both free and attached to biofilm communities that form on the surface [sand layer] and sand grains (Huisman and Wood, 1974). The biofilm is derived initially from the biology in the raw water and is subsequently sustained by the organic matter in the raw water (Ritenour, 1998).

Biologically mediated mechanisms, together with physical-chemical mechanisms, account for removal of particles smaller than about 2 um in diameter (Weber-Shirk and Dick, 1997). [As influent water penetrates the standing water reservoir, m]otile predators either living in the supernatant or in the sand surface travel upward [] due to the new more abundant food source. Many faecal indicator organisms and pathogens will be consumed here (Buzunis, 1995). Predation by protozoa has been identified as the principle biological removal mechanism of harmful bacteria in source water.[1] Physical-chemical removal processes include straining (of particles greater than about 2 um in diameter) and attachment via intermolecular forces between the sand grain surfaces and dissolved and/or suspended particles.

Zone of Biological Activity

The depth of the pitcher filter fine sand layer is approximately four and a half times less than that of the Davnor BioSand filter. However, the reduced flow path length is not expected to result in smaller microbial removal efficiencies as long as the 5 cm supernatant depth is maintained. Buzunis (1995) found sand layer depth to be inconsequential except for the increased headloss and reduction of flow provided by a deeper sand bed. The depth of the [filter's] biological layer [i.e., biological removal region] is mainly a function of the *depth of water over the sand bed* since this controls the rate at which oxygen can be drawn down to the biologically active zone and the depth into the sand oxygen can be supplied. While the intensely tested [BioSand] filter had a biologically active zone less than 10 cm in depth, in filters with a more shallow standing water depth the biologically active layer is expected to be deeper. This would result in a longer contact time with the filter biology and improved filter efficiency (Buzunis, 1995).

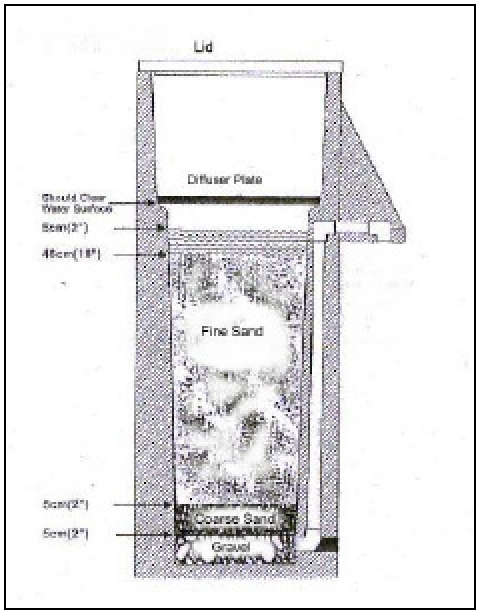
[1] Weber-Shirk and Dick (1997) studied particle and E. Coli removal mechanisms in slow sand filters. Introduction of sodium azide (an inhibitor of oxidative phosphorylation) was found to cause appreciable reduction in particle and E. Coli removal, indicating biological removal mechanisms to be significant. Bacterivory was identified as the biological mechanism principally responsible for bacteria removal.

Work to Date

Nepal BioSand Pitcher Filter Experiments

<u>Methodology</u>

Field experiments at the International Buddhist Society in Lumbini, Nepal, were performed over a 4 day period. The purpose of these investigations was to conduct a preliminary evaluation of pitcher filter viability by cross-checking their performance with the concurrent performance of concrete BioSand filters.



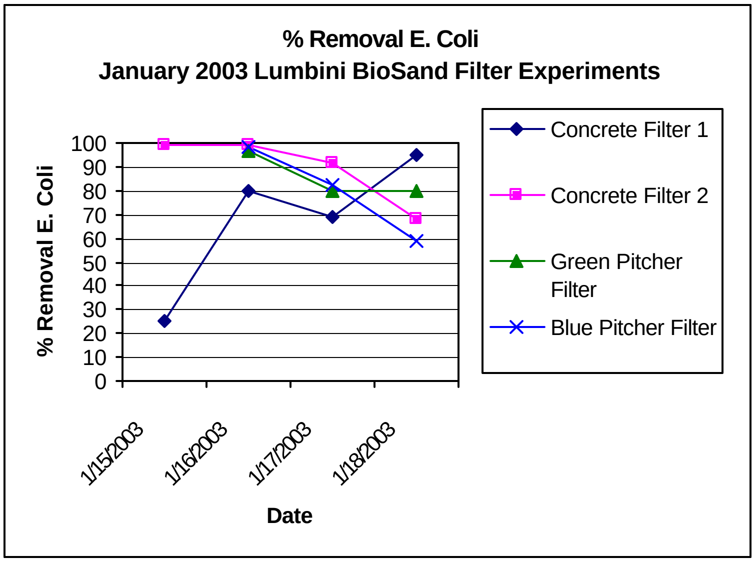
Davnor concrete BioSand filter

Each filter was challenged with 2 L of E. Coli rich source water per day, and subsequent performance evaluated. Filter performance was evaluated using enumeration of E. Coli bacteria removal, presence/absence tests for H_2S producing bacteria, turbidity and flow rate measurements.

Source water for pitcher filters was obtained from a stagnant, highly turbid pond on IBS property. Raw water E. Coli concentrations varied from at least 400 cfu/100 mL to at least 1000 cfu/100 mL.

<u>Results and Project Implementation</u>

Microbial removal performance of Lumbini pitcher filters was comparable to that of the concrete BioSand filters. On January 16th, source water for all filters contained at least 500 cfu/100 mL E. Coli. Concrete filters 1 and 2 (CF1 and CF2, respectively) removed 99.8% and 80% of influent E. Coli, respectively; removal efficiency for the green and blue pitcher filters was 97% and 98%, respectively. Impressively, performance of both pitcher filters surpassed that of CF2 on this day.



Microbial removal efficiency of the BF did decrease to 59% on the last day of testing (January 18th), however, performance of CF2 also declined on this day – to 68% from 92% the previous day. This decline may be attributed to lower quality influent water used on the last day of testing. E. Coli concentrations in pitcher filter influent water increased by at least 155 cfu/100 mL from January 17th to 18th; an increase of at least 55 cfu/100 mL was observed for CF2. A larger increase in E. Coli concentrations for CF1influent water was observed: concentrations increased from at least 75 cfu/100 mL to at least 413 cfu/100 mL. However, removal efficiency of CF1 increased from 69% to 95% on January 18th. The higher concentrations of E. Coli in the CF1 January 18th influent water may correspond to higher levels of dissolved organic matter. These organic substances may have stimulated biofilm development and facilitated E. Coli removal.

In general, microbial removal performance for all filters was high, but variable. Further testing would have been necessary to verify actual trends in microbial removal capacity and determine relative contributions of random variability to data skewing.

Pitcher filters appeared equally effective at removing suspended particles as concrete filters, and may have even surpassed the latter in turbidity removal capacity. While turbidity removal averaged 91.0% for the GF and 92.6% for the BF (as compared to 89.3% for CF1 and 93.0% for CF2) turbidity of pitcher filter source water was approximately three times that of concrete filter source water. In summary, pitcher filters were treating water of much higher suspended solids content than the concrete filters, but still had approximately identical turbidity removal.

MIT BioSand Filter Experiments

Methodology

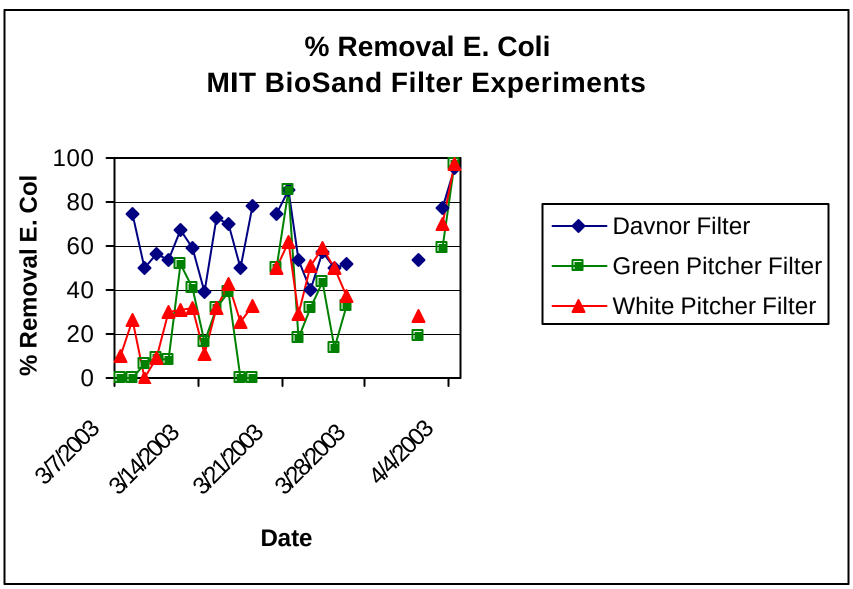
Laboratory experiments were performed to compare the performance of two BioSand pitcher filters, a green pitcher filter (MIT-GF) and a white pitcher filter (MIT-WF), with a Davnor plastic BioSand filter (MIT-DF, Davnor, 2002).

Twenty-nine days of filter experiments were conducted (March 7th – April 4th). Source water was obtained daily from the Charles River, in Cambridge, Massachusetts. River water was spiked with fresh E. Coli cultures grown during the previous night.

On April 3rd and 4th (the 28th and final day of experimentation, respectively), filters were challenged with a 1:1 mixture of room temperature Charles River water and waste water from the Deer Island Wastewater Treatment Plant in Boston, Massachusetts.

Results and Project Implementation

For the period of March 7th to April 2nd,filters were challenged with room temperature Charles River water spiked with E. Coli bacteria. During this time, E. Coli concentrations in influent water varied from 4 to 345 cfu/100 mL, averaging 87 cfu/100 mL (target concentration was 100 cfu/100 mL).



A generally upward trend in microbial removal efficiency was observed for the period of March 7th – March 21st (days 1 – 15 of experimentation). Removal efficiencies for the green and white pitcher filters (MIT-GF and MIT-WF) increased from 0% and 10% on March 7th to 85% and 62% on March 21st, respectively. These data points correspond to increases in Log_{10} Reduction Values (LRVs) of 0.0 to 0.8 and 0.0 to 0.4, respectively. Removal efficiency for the Davnor filter was 75% on March 8th (LRV of 0.6), but subsequently declined to 50% (LRV of 0.3) the next day. Removal performance gradually increased over the course of the next 12 days to 85% (LRV of 0.8) on March 21st.

On March 22nd, E. Coli removal efficiencies for all three filters dropped significantly. Removal efficiencies for the Davnor and green pitcher filter both dropped from 85% on March 21st to 54% and 18%, respectively, the next day. These values correspond to 36% and 79% reductions in performance, respectively. The white pitcher filter experienced a 53% drop in performance, from 62% to 29% removal. This drop in performance may have been due to disturbance of the biofilm. Though the author was frequently the only person working in the laboratory, the work space was utilized by department classes at other times. Jostling of the filters and subsequent disturbance of the surface biological community could have caused the drop in performance observed.

For the 11 days following (March 23rd – April 2nd), microbial performance for all three systems remained relatively static; a slight upward trend until March 24th was detected, with subsequent declines in removal efficiency. The Davnor filter showed variable performance around 50% removal, with a high of 57% on the 24th but the April 1st data point at the March 22nd value (54%). Similarly, the green pitcher filter showed increasing microbial removal performance from 18% on the 22nd to 44% on the 24th, then a decline to 19% on the 1st. Removal efficiency for the white pitcher filter increased from 29% on March 22nd to 59% on the 24th, then decreased to 28% on the 1st.

On April 3rd and 4th, the filters were challenged with a 1:1 mixture of Charles River water and wastewater obtained from the Deer Island Wastewater Treatment Plant (Boston, Massachusetts). Raw water E. Coli concentrations for these days were 1813 cfu/100 mL and 1188 cfu/100 mL, respectively, averaging approximately 1500 cfu/100 mL. Microbial removal performance for all filters improved dramatically in response to this influent. Removal efficiency for the Davnor increased by 30%, from 54% on April 1st to 77% on April 3rd. These data points correspond to a LRV increase of 50%, from 0.3 to 0.6. Similarly, a 68% increase in removal efficiency (75% increase in LRV) was observed for the green pitcher filter, and a 60% increase (80% increase in LRV) for the white pitcher filter.

Impressively, pitcher filter performance surpassed that of the Davnor filter on April 4th, the last day of experimentation. The green and white pitcher filters both reduced influent E. Coli concentrations of 1188 cfu/100 mL to 40 cfu/100 mL, a 97% removal rate (LRV of 1.5), compared to a 95% reduction (LRV of 1.3) for the Davnor filter to 60 cfu/100 mL. Further testing would have been necessary to verify that these high removal efficiencies were not transient responses to influent water quality but truly indicative of filter performance.

Areas Meriting Further Investigation

Preliminary results from pitcher filter investigations are encouraging. Pitcher filter microbial removal performance appears comparable to Davnor filter performance. Even so, more comprehensive testing of the technology is appropriate. In particular, the following areas merit further investigation:

- What is the optimal holding capacity for the pitcher filter? That is, to what extent does decreasing the depth of the fine sand layer (and thus increasing liquid holding capacity) affect microbial removal?

- Because of their small size, the pitcher filter biofilm may have a greater risk of disturbance (i.e., from jostling) than that of the heavier concrete or plastic BioSand filter. To what extent do slight disturbances affect microbial removal performance of the pitcher filter system?

- To what extent does increasing or decreasing the distance between the supernatant surface and the diffuser plate affect microbial removal performance?

- How is microbial removal performance of the pitcher filter affected by pause times? Are these effects comparable to those experienced by concrete filters?

- How feasible is a low-tech accelerated ripening approach consisting of challenging pitcher filters with lower quality water (e.g., dilute wastewater) prior to daily use? What sorts of time-frames should be considered for this method (days, weeks, etc.)?

Concluding Remarks

Access to safe water is a basic human right that has been denied to a large proportion of the world's population. Only 0.7% of the world's water supply is available for consumption and, unfortunately, it is disproportionately distributed. Over one half of the people living in developing countries suffer from diseases related to unsafe water supply and sanitization (Samaritan's Purse, 2002). At the beginning of 2000 one-sixth (1.1 billion people) of the world's population was without access to improved water supply. The majority of these people live in Asia and Africa, where fewer than one-half of all Asians have access to improved sanitation and two out of five Africans lack improved water supply. These figures are all the more shocking because they reflect the results of at least twenty years of concerted effort and publicity to improve coverage (WHO, 2000).

The use of polluted waters for drinking and bathing is one of the principal pathways for infection by diseases that kill millions and sicken more than a billion people each year (World Bank, 1992). Unsafe water is implicated in many cases of diarrheal diseases. Approximately 4 billion cases of diarrhea each year cause 2.2 million deaths, mostly among children under the age of five. This is equivalent to one child dying every 15 seconds, or 20 jumbo jets crashing every day. These deaths represent approximately 15% of all child deaths under the age of five in developing countries (WHO, 2000).

The most widespread contamination of water is from disease-bearing human wastes, usually detected by measuring fecal coliform levels. Human wastes pose great health risks for the many people who are compelled to drink and wash in untreated water from rivers and ponds (World Bank, 1992). Fecal contamination of source and treated water is further exacerbated by increasing populations, urban growth and expansion, peri-urban settlement and continued and perhaps increasing pollutant transport into ground and surface water due to deforestation, global climate change, recurrent disastrous weather events (hurricanes, cyclones, floods, tsunamis, etc.) and increasing coverage of the earth's surface with impervious materials (Sobsey, 2002).

There is now conclusive evidence that simple, acceptable, low-cost interventions at the household and community level are capable of dramatically improving the microbial quality of household [] water and reducing the risks of diarrheal disease and death in populations of all ages in the developed and developing world (Sobsey, 2002). Developed specifically to address local needs and with much local support, BioSand pitcher filtration technology has much to offer the developing world as a purveyor of safe household drinking water.

Implementation

June – Sept

- Comprehensive laboratory testing at MIT.
- Laboratory space to be provided by Susan Murcott, Department of Civil and Environmental Engineering.

Oct – Jan

- Field work in Nepal.
- Collaboration with IBS women motivators (health workers) to set up pitcher filters in villages, with weekly monitoring to evaluate field performance.
- Workshops to educate users on filter operation and maintenance. IBS women motivators to act as translators.
- Pending results, dialoge with Kathmandu based NGO, Samaritan's Purse, and ENPHO – Environment and Public Health Organization to organize additional pilot projects, train technicians, etc.

Feb

- Additional laboratory investigations at MIT, if necessary.
- Soping for additional funding.

Biography

Melanie Pincus obtained her Bachelor's Degree in Civil and Environmental Engineering at MIT in June 2002, and is currently pursuing her Master's at MIT in the same field. Fields of expertise include environmental chemistry and contaminant transport, and anti-pollution law and control.

Budget

General
Sterilization

Quantity	Description	Total Cost
	Methanol	5.00
2	Squeeze Bottles for Sterilized Water and Methanol	5.00
	Lighter	0.50
	Stove for sterilizing glass and heating incubator	100.00
	Pot for sterilizing glass	20.00
	Hand sanitizer	20.00
2	Cooler/Refrigerator	10.00
2	Ice packs for transport	10.00
Incubation		
1	Amy's Incubator (for 20 mL glass bottles - holds 24)	
1	Pocket Thermometer (-30 to 50^{o}C)	17.15
1	Single Chamber Incubator (230V)	
1	Power cord (230V)	
3	Nickel Cadmium battery	190.00
2	Battery Charger (230V)	
1	Fast acting fuses (3/4 Amp, 250V, 5X20 mm, GMA-type) 4/pk	10.00
Sample Collections		
1	Metal stirrer	2.00
1	100ml polypropylene Graduated Cylinder	5.00
1	25 mL capped glass graduated cylinder	5.00
1	50 mL glass graduated cylinder	5.00
5	250 mL polypropylene sampling bottles	5.00
1	Stop Watch	
1	Screwdriver (flat head)	5.00
1	Screwdriver (Phillips head)	5.00
0.5	Lab marking pens (permanent), fine tip 10/pk	8.27
0.25	Lab Labeling tapes, rainbow pack of 16, 3/4 in width	13.58
0.25	Lab Labeling tapes, rainbow pack of 12, 1 in width	12.96
10	Whirlpack bags-100ml-100/pk	350.00
Dilutions		
1	Authomatic Pipette, autoclave 0.1 uL to 10 mL	50.00
1	Pipette tips 250 /pk	10.00
1	100 mL glass volumetric flask	2.00

Turbidity

1	Pocket Turbidieter	
20	AAA Batteries for turbidimeter	20.00

Membrane Filtration

1	Patch Test assembly Holder #1	
1	1/8 in viton tubing for vacuum #1	
1	Hand pump #1	
1	250 mL Stainless Steel Cup #3	
1	S-Pak Filters 0.45 um 47 mm 200/Pk	30.00
8	petri dishes with pads 20/Pk	30.00
1	tweezers	
4	m-ColiBlue 24 Broth 50/Pk	40.00

H2S P/A Sachet

10	Patho Screen Medium MPN Pillows 20 ml samples 25/pack	230.00
50	20 ml glass samplig bottle	50.00

Prototype Materials

Plastic pitchers	105.00
Sand	
Plastic viton tubing	10.00
Metal ties	2.00

Round-trip plane ticket to Nepal	1,800.00
	3,183.46

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