Experimental Studies in Developing Safe Sanitation Solutions

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Abstract

Worldwide, 2.4 billion people lack access to in-home toilets, hampering health and development. Cramped living spaces without plumbing make traditional toilets infeasible in poor countries. Significant strides have been made towards economic alternatives. One promising option is a 2-pit composting toilet, 61 of which have been installed in a village in India.

In this toilet, solid waste is effectively treated through anaerobic composting. Concerns remain regarding the impact of liquid waste on drinking-water. The design uses a honeycomb-brick structure surrounded by sand, acting as a Slow-Sand-Filtration (SSF) system. Initial analysis suggests that SSF alone is insufficient at removing fecal coliform contaminants.

Second objective involves determining economic additives to SSF systems. The efficacy of these potential additives in removing fecal coliform bacteria was tested using table-top prototypes, constructed as plug-flow reactors; heterotrophic plate-count method was used to compare bacterial concentration in simulated human waste before and after treatment. In Phase I, addition of pebbles to SSF was found to be 83% more effective. In Phase II, design constraints for liquid additives were evaluated. Experimental data is presented and future steps enumerated.

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Key Words

Slow-Sand Filtration (SSF), fecal coliform, plug-flow reactors, sustainable toilets, human waste management, natural antimicrobials, open defecation, anaerobic decomposition, Heterotrophic Plate Count method

Abbreviations and Acronyms

Slow Sand Filtration (SSF), Total Coliform (TC), Most Probable Number (MPN)

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Biography

Nishita Sinha is a current junior at Chatham High School, NJ. Every year, Nishita visits her ancestral village in Payagpur, North India, where her grandmother still resides. A few years ago, Nishita noticed groups of women traveling far into the fields to defecate early in the morning and late at night. After doing a bit of research, Nishita realized how dangerous open defecation could be. So, two years ago, as a part of her Girl Scouts Gold Award, Nishita started looking for sustainable and inexpensive toilet options and gravitated towards the Sulabh International 2-pit Composting Toilet because of its major cost, space, and maintenance advantages. She secured support from individual and charitable organizations and facilitated the installation of 61of these toilets. The author's objective was to install one system per family in order to encourage a sense of responsibility and ownership to facilitate toilet maintenance. Initially, the goal of this project was purely driven by social objectives, not rooted into scientific research. However, as she became more familiar with the intricacies of the Sulabh design and observed its installation, Nishita became increasingly concerned about how these toilets handled liquid waste. With the help of her AP Chemistry teacher and later on, professors at Rutgers University, Nishita started lab work to improve upon these toilets. Nishita has presented her work and won multiple awards at the North Jersey Regional Science Fair (NJRSF), Junior Science and Humanities Symposium (JSHS), and the International Sustainable World Energy, Engineering, and Environment Project Olympiad (I-SWEEEP) in Houston, Texas. She looks forward to continuing and expanding this project to help villagers in her ancestral village and perhaps other areas around the world.

Introduction

Lack of proper sanitation is a serious issue that affects 2.4 billion people worldwide. Close to 50% of hospital beds in developing countries are filled by people suffering from diseases related to poor sanitation, and five hundred thousand children die every year because of unsafe water conditions [1]. In addition, due to the lack of proper sanitation systems at schools, young women in particular stop attending school once they hit puberty [2]. Though often overlooked, unsafe sanitation is one of the major problems preventing progress in the developing world.

A specific form of unsafe sanitation prevalent in the developing world arises from the lack of in-home toilet facilities for large segments of population, which results in open defecation by millions of people (see Table 1). Some of the major diseases associated with such practices are Cholera, Diarrhea, Dysentery, and Hepatitis A viral infection [3]. Without proper means of disposing of human excreta, enteric pathogens are spread by insects such as house flies and also tend to get into wells or other groundwater supplies. Through this contamination, the diseases caused by these bacteria, viruses, and parasites get passed onto other hosts [4][5]. Of course, these diseases do not affect all the regions evenly. For instance, *Vibrio cholerae*, the bacteria that causes Cholera, prefers a wet, tropical climate and therefore Cholera is highly prevalent in Southeast India and Bangladesh. Because of this penchant to rainy environments, *Vibrio cholerae* proliferates during monsoon season and becomes less active during drier periods [6]. When developing solutions to these problems, it is important to account for these regional and seasonal differences.

Country	Number of People who Practice Open defecation	Percent of Open Defecation in the World
India	626 million	70.43%
Indonesia	63 million	7.09%
Pakistan	40 million	4.50%
Ethiopia	38 million	4.28%
Nigeria	34 million	3.83%
Sudan	19 million	2.14%
Nepal	15 million	1.69%
China	14 million	1.58%
Niger	12 million	1.35%
Burkina Faso	9.7 million	1.09%
Mozambique	9.5 million	1.07%
Cambodia	8.6 million	0.968%

Table 1 (data from World Health Organization [7]): Open Defecation World Wide

Though open defecation overwhelmingly affects rural villages in India, it is a problem among large populations across the developing world.

The author had the opportunity to observe and verify the problems of open defecation first hand. In a group of villages in Payagpur, Uttar Pradesh, India, visited and studied by the author, open defecation is commonplace. In a survey of a stratified sample of 30 households conducted by the author, 25 out of the 30 reported that it was normal for at least one family member to have diarrhea or another stomach or intestinal illness at any given time. These diseases are known to spread primarily due to the transmission of fecal coliform bacteria from waste to the groundwater supply of drinking water, which demonstrates the severity of the problem.

In looking for solutions to this issue, the author realized that, in the past few years, there has, in fact, been a significant wider push to develop and deploy safer and economical toilet systems in the developing world by government and private organizations. In 2011, the Bill and Melinda Gates Foundation hosted the Reinvent the Toilet competition to address this worldwide issue, with the goal of designing a sanitation system feasible for use in rural settings in developing countries [8]. Many of these rural settings share a couple of common traits, which make toilet solutions that are readily available in the western world impractical for deployment there; these are: (i) constraints on the space available for building toilets because people tend to live in densely populated clusters while most of the surrounding land is committed to agriculture [9], (ii) lack of a well-planned drainage system and the use of hand-pumps to draw drinking water from relatively shallow depths of 4.5 to 10 m from the ground, leading to a high risk that untreated waste, particularly liquid waste, ends up contaminating the drinking water [10].

Many innovative toilet designs were introduced during the Gates Foundation competition to address these challenges, and a common theme that emerged was the utilization of composting. Solid waste composts naturally into usable fertilizer and methane gas, so it becomes easy to manage and reap benefits from human waste [11]. Winning systems such as the California Institute of Technology’s toilet system handle solid waste using such techniques, and additionally utilize reverse osmosis as a liquid purification technology [12]. This successful process uses pressure and a semi-permeable membrane to purify urine. However, although these new designs were undoubtedly groundbreaking, the implementation of these toilets has proven impractically expensive in many cases.

After reviewing tens of these and other available systems, a 2-pit composting toilet system manufactured by Sulabh International [14] was chosen by the author due to its affordability, space efficiency, and low maintenance cost. As noted above, 61 such units were installed during the initial social phase of this project.

In order to better understand the advantages as well as the potential issues in this selected Sulabh toilet system, a review of its design is beneficial. Schematic of this system is shown in Figure 1. As seen, it uses a two pit underground system to handle waste. Surrounding each pit is a honeycomb brick structure. At first, waste is only allowed to flow into one pit. As waste enters the pit, solids settle at the bottom. After one pit fills up completely, which may take about 3 to 5 years, it is closed off and the effluents are directed into the second pit. In the closed off pit, solid waste anaerobically decomposes into safe, odorless fertilizer, which can be harvested from the pit in 1-2 years.

Although the management of solid waste appears to be a forte of the Sulabh 2-pit design, the management of liquid waste caught the author's attention. As the waste fills up in each pit, liquid waste, possibly containing bacteria and dissolved solids, flows side-wards through the honeycomb-brick structure of the pit wall and into the surrounding soil. Aware of this potential issue, Sulabh incorporates a 0.15m filtering layer of sand between the honeycomb-brick structure and the soil. This serves as what is known as an all-natural Slow Sand Filtration (SSF) system. Under ideal conditions, the SSF successfully filters pathogens out of liquid waste before it is discharged into the surrounding soil. However, the author could not be sure about the SSF efficacy, and this spurred the first scientific study of this project – to make a definitive conclusion regarding SSF efficacy.

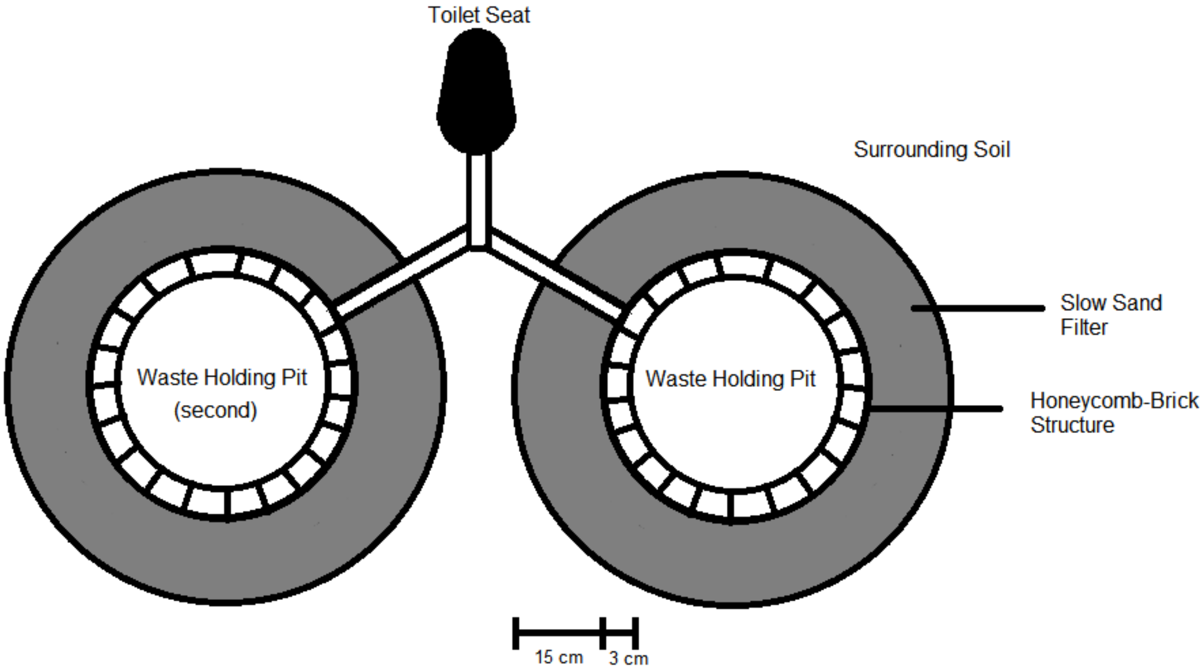


Figure 1: Sulabh International Two-pit Composting Toilet diagram

This concern stemmed from the following reasons. In the village where units were installed, the effluent leaves the filter at a depth of approximately 1.8 m underground [14]. But, groundwater tables reach up to just 4.5 m below the ground. Similar conditions are prevalent in rural villages across large parts of India and other countries. Because of the close proximity between the toilets and water supply, it is important for the liquid effluent entering the soil to have as little fecal coliform as possible. This is why it is essential for the SSF to filter effectively. A disadvantage of SSF filters is that they require a lot of space to effectively remove large amounts of bacteria contaminants. Space, i.e. the required thickness of the SSF layer for effective filtration, varies based on application, but for conditions in the village of interest, a 5 - 10 m thick sand layer would generally be considered safe for fool-proof filtration efficacy [1][13]. This safe space requirement is clearly impractical given the tight living conditions of these communities, as mentioned above. The Sulabh International System, for instance, employs a SSF layer of only about 0.15 m.

The present research is being conducted in several phases. In the first phase, which has now reached culmination, the goal was twofold. First, studies were conducted and results analyzed regarding the efficacy, or lack thereof, of the SSF as used in the Sulabh System with a practical width of about 0.15 m. Next, attempt was made to establish that SSF filter efficacy can be improved substantially by using commonly available additive and identify at least one such simple additive for which improvements can be established. In other published studies pebbles and pieces of branches have been used to improve drinking water quality and turbidity while other substances like essential oils have been shown to have effective antibacterial properties [15][16]. Therefore it was hypothesized that these readily available materials, when mixed with sand, could also be applied to improve the efficacy of wastewater filtration in the toilet systems of interest. Specifically, pebbles were chosen as the first additive for the sake of Phase I research. This paper presents the methodology developed for the evaluation of different filter designs and the results of Phase I studies pertaining to efficacy data for two different mixtures of filter substrates – i.e. a pure sand based system and a second sand and pebble mixture.

Once it has been established that SSF filter efficacy can be improved using simple yet effective technique of using additives, we now move to a broader study of several other additives as part of a Phase II research. In Phase II research, in addition to in lab improvement, we are also evaluating long term efficacy of additives when placed in the real-world geometric configuration employed by the Sulabh 2-pit toilet system. Initial details related to Phase II research are also included in this paper.

Experimental Method and Setup

The first step in this work was determining how to best construct prototype table-top filters to model SSF. As shown in Figure 1, in the Sulabh toilets, liquid waste with dissolved particles and bacteria is horizontally filtered out through the layer of sand. However, for the prototype filter systems developed for this work, vertical filtration was decided upon, as it was found to be most practical for side-by-side comparison of different type of filters. Polyvinyl chloride (PVC) pipe was chosen as the body of the prototype filter. PVC pipe is sturdy enough to support sand and added materials and is easy to clean between trials. A detachable stainless steel mesh strainer was mounted at the top of a PVC section to mimic the honeycomb-brick structure of the filters in the original Sulabh systems. A funnel was installed at the bottom to make collection of the effluent easier. Plastic wrap was then used to ensure the filters are water tight. Two identical filters were constructed, one to be used as a control filter to provide a basis for comparison and the second one to test various filtering materials.

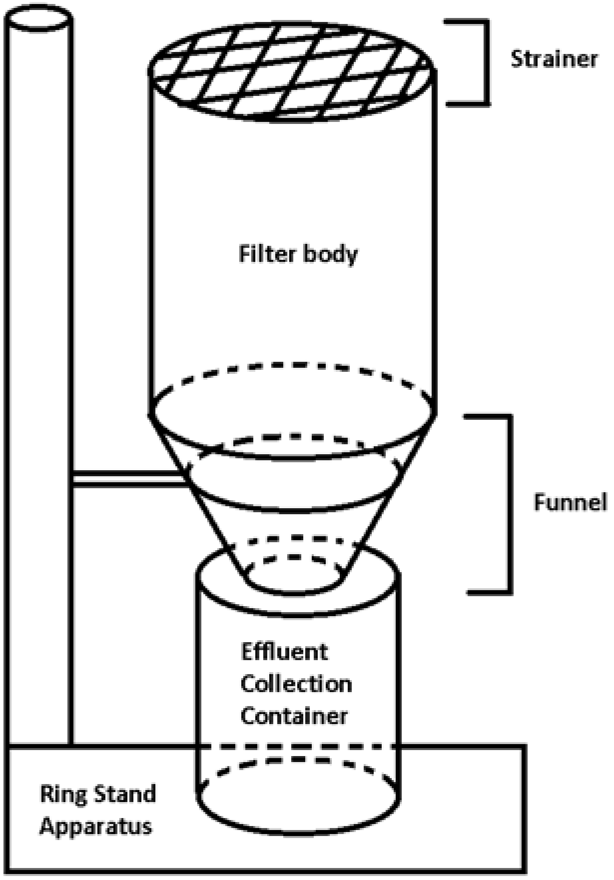


Figure 2: Filter Design - a diagram of the filter setup

Volume - Filter Body: 1914 mL

Volume - Funnel: 365 mL

Total Volume: 2279 mL

Figure 2 shows a schematic of the two prototype filters used in this work. The first control filter was filled with a 100% sand substrate. This reference sand mixture was created from very fine sand mixed with coarse sand in a 17 to 3 ratio by volume. When wet, this mixture had a density of 1930 kg/m^3. The second filter contained the reference sand mixture used in the first filter further mixed with pebbles in a 1.5 to 1 ratio by volume. This substrate had a density of 2022 kg/m^3 when wet. The sand samples were obtained directly from the target Indian villages where the Sulabh toilet installations have already progressed. Both filtering substrates were soaked thoroughly with 2.0 L each of 0.9% saline solution prior to starting experiments.

It was of paramount importance to accurately simulate the waste that goes into the filter systems in real life viz. human urine and feces. Tap water with 0.9% of kosher salt by mass was used to simulate human urine. Mashed potatoes were used to simulate feces. The viscosity of mashed potatoes and its accessibility make it a very good alternate for actual feces [17]. Saline solution was mixed with mashed potatoes in a 4 to 1 ratio by volume. Finally the simulated human waste was "contaminated" with 1x10^6 cells/gram of *Escherichia Coli* (Genotype B), ATCC® 23848 bacteria. These cells were grown by inoculating Nutrient Broth (Difco) with *a* freeze-dried stock of *E. coli* and incubating it for 24 hours. Initial concentration of this culture was estimated using the spectrophotometer by measuring absorbance of yellow light (wavelength 525 nm).

Before starting the runs, 50 mL of the influent simulated waste sample was set aside to represent the untreated waste. This serves as a reference for both the control (pure sand) and test (sand-pebble mixture) filters. To accurately model and measure real-life efficacy of the filters, the sample collection needs to be spread over multiple runs. This is primarily due to the fact that as more and more waste is passed through the filters during each run, or during continuous usage in a real-life scenario, bacteria from an earlier bout of waste captured in the filtering substrates can get pushed down the filter body and eventually "breakthrough" into the effluent. Detection and study of any such breakthrough is important to the comparison of filtering efficacy of different substrates. In order to measure longevity of each filter and observe the breakthrough, a large amount of waste typically needs to be passed through each filter.

This was accomplished in the following fashion. The influent synthetic waste was added into the filter in 0.25 L increments during each run. For each such 0.25 L sample, the first 0.05 L of the filtered output was collected at the bottom of the prototype filter, and subsequently refrigerated in labeled vials, while the remaining ~0.2 L was allowed to pass through and discarded without collection. To obtain additional data for breakthrough point determination and filter comparison, one 1.0 L and two 0.5 L samples of saline solution were then passed through the filter after the five initial runs with simulated human waste; 0.05 L of output was collected at the end of each of these 3 “post-runs”. Retention time, or the time measured from when the influent was added to when all effluent passed through, was also recorded for each run. All samples were added without cleaning the filtration apparatus in between in order to realistically model real-life situations and obtain sufficient data for longevity comparison.

Total Coliform (TC) concentration in each of the collected samples was determined using the standard Heterotrophic Plate Count method [18]. First, a sterile filtration apparatus was set up with a membrane filter. After dilution of the influent sample with distilled water in a 1:100 ratio, 0.05 mL, 0.1 mL, and 0.5 mL of the influent sample and 0.5mL, 5.0 mL, and 25.0 mL of all non-dilute effluent samples were filtered and aseptically transferred to m-Endo agar petri dishes and incubated at 35°C for 48 hours. Coliform bacteria are lactose-fermenters that produce red-metallic colonies on m-endo agar [19]. These colonies were counted to determine the Most Probable Number (MPN) of TC colonies per 100 mL for each sample.

In Phase II we have planned to study two new additives, canola oil and garlic paste. Due to its consistency, canola oil was chosen as a locally obtainable alternative for coconut oil and mustard oil. The latter two oils are readily available in India and have known antimicrobial properties against enteric pathogens [21][22]. As a second additive, garlic paste was chosen due to its well known antimicrobial properties, which stem from sulfuric compound allicin in the short terms , and adjoene in the long term [23]. Since real-life efficacy is also of interest in this Phase, attention is being paid to the durability of the additives. In Figure 1 the Sulabh sand filter layer is 2-meters in height. Materials such as oils and pastes can flow down the sand layer and settle at the bottom. If these materials flow downwards too quickly, the filter efficacy at the top of the sand layer would likely be compromised. To study this potential problem, the author has constructed three second generation longer reactors and has begun tests to determine the downwards flow rate of different additives. These reactors were constructed from PVC pipe (see Figure 3).

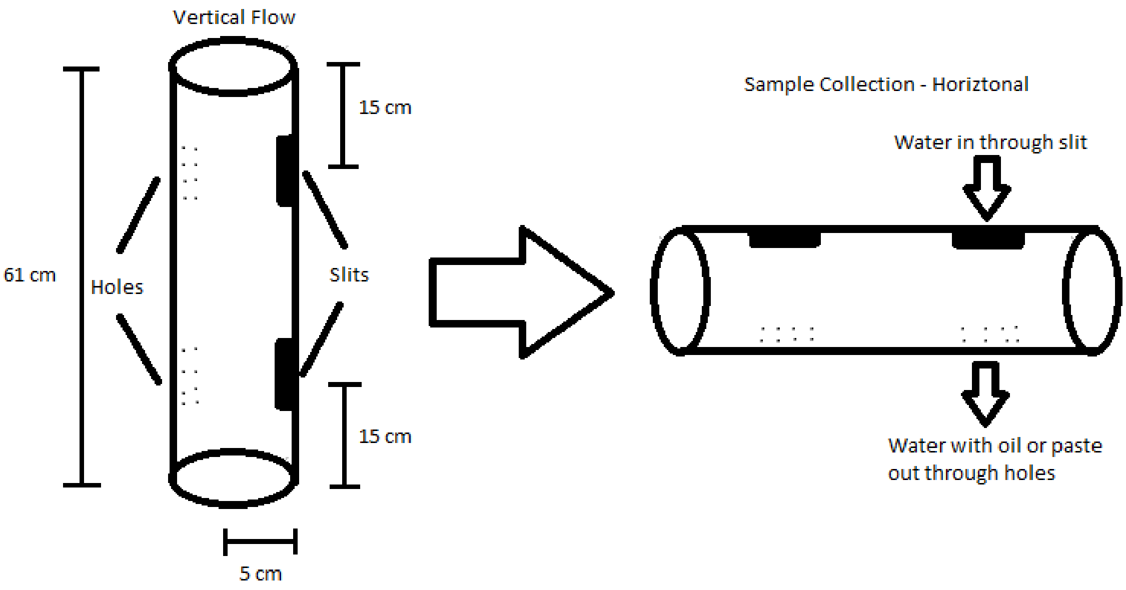


Figure 3: Generation 2 Model: Set up vertically to study the downwards flow of additives, turned horizontally to collect samples from different locations within the reactor.
Volume: 4.8 L

Initially, the slits and holes (shown in Figure 3) are covered. The reactors will be filled with sand mixed evenly with canola oil or garlic paste and set vertically so that gravity has its impact. Every 1-2 days, each reactor will be turned on its side (with the slit side up) and the slits and holes will be uncovered. 300 mL of water will be passed through each slit and collected from the adjacent holes. Then, the holes and slits will be covered and the filter once again turned vertically. Each effluent sample is to be tested for the amount of either oil or paste present. Collecting these samples near the top and bottom of the reactors provides a good approximation for how fast the oil or paste has traveled down the filter.

The author is currently performing these trials for canola oil. The presence of oil in effluent can be detected by the presence and size of an oil layer above the water. Concurrently, the author is developing the method to detect the chemical signature of garlic paste using spectrophotometry. Based on available materials, the first step is to determine if the absorbance of garlic showed a “peak” in the visible light range (wavelengths of 400 – 700nm). The purpose of this is to determine if visible range spectrophotometry can be used to effectively measure garlic concentration in effluent. Garlic paste was prepared by crushing cut garlic pieces to realize juices and then filtering out particles.

Experimental Results

Phase I: Efficacy of Sand and Sand+Pebbles Filters

Figure 4 shows the TC colony strength in the collected samples for the first 3 experimental runs of the each of the two filters. Figure 5 shows the TC colony strength data for these as well as subsequent runs, providing insight into longer term efficacy of the two filters. Figure 6 shows data for smaller increments of influent waste added to the filters.

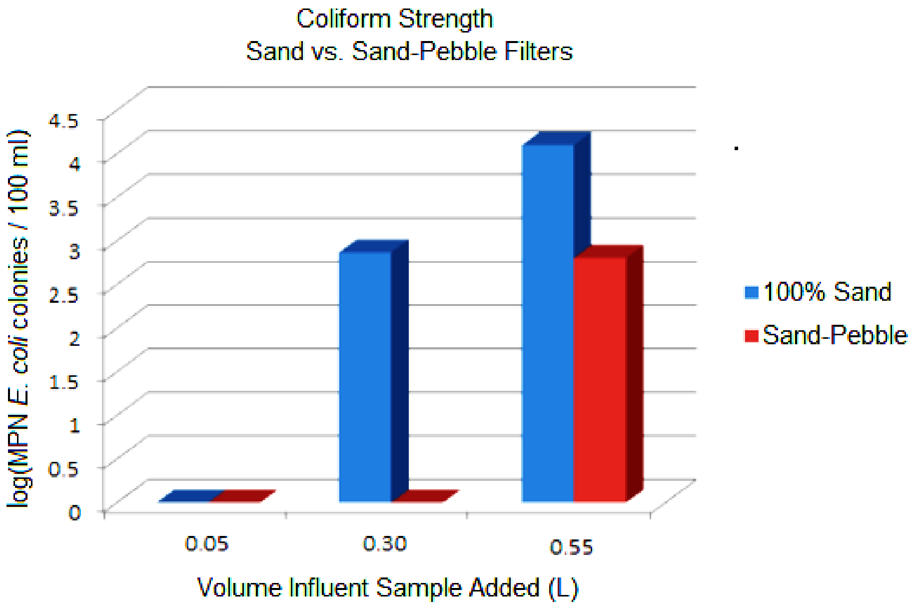
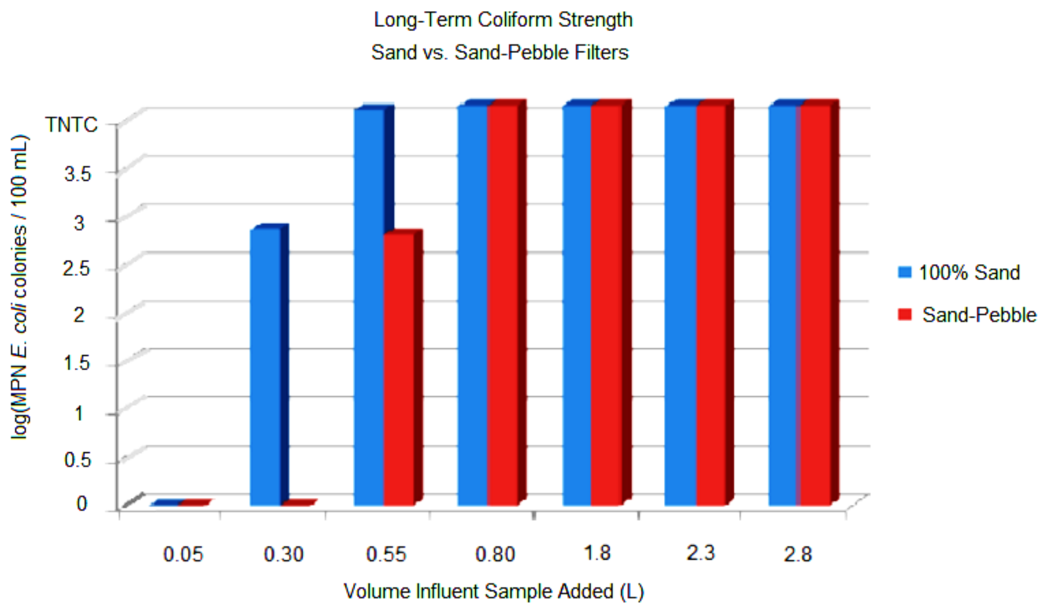


Figure 4: Coliform Strength (Most Probable Number [MPN] *E. coli* colonies/100 mL) vs. Volume of Influent Waste Added for the first 3 experimental run.



TNTC = Too Numerous To Count

Figure 5: Coliform Strength vs. Volume of Influent Waste Added for several runs including the "post-runs"

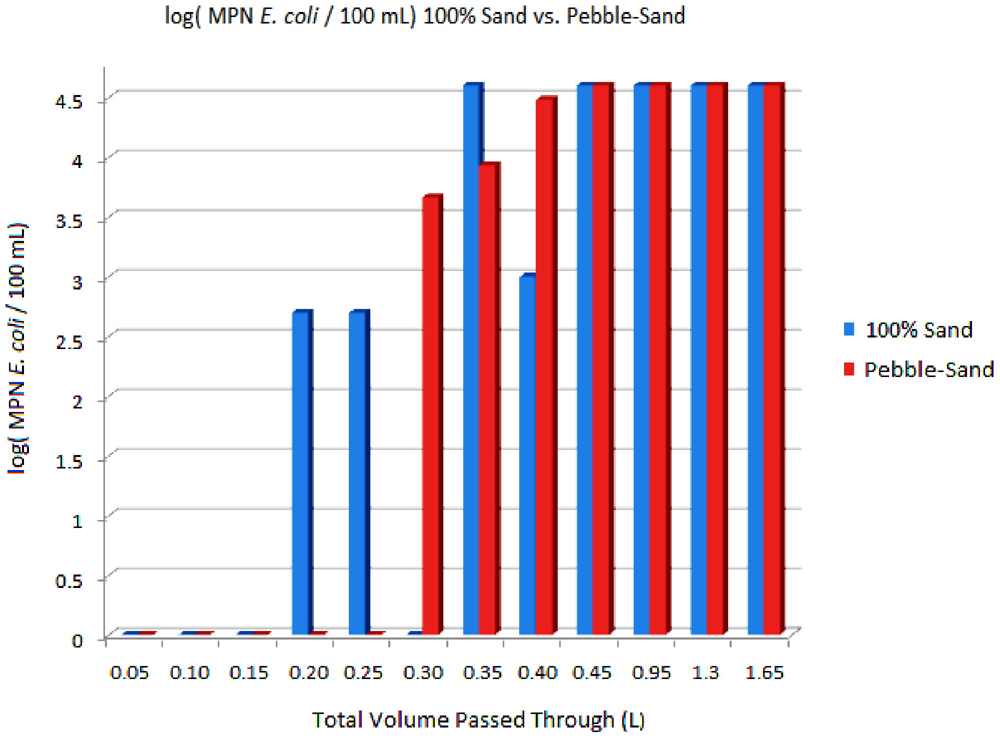


Figure 6: Coliform Strength vs. Volume for smaller increments of influent waste added.

It can be seen from Figures 4, 5, and 6 that for both the pure sand filter and the sand-pebble filter, no fecal coliform colonies were observed in the effluent collected after passing through 0.05 L of waste. Colonies started to appear after passing through 0.3 L of waste for the pure sand filter – i.e. from the second run, and after passing through 0.55 L for the sand-pebble filter – i.e. from the third run. In several successive trials, the sand-pebble filter typically continued to have less colonies than the pure sand filter, but the bacterial colonies in the effluent of both filters reached levels in the high thousands (or too numerous to count) after passing through about 0.8 L of waste.

It is interesting to note that the retention time of each filter progressively increased. The pure sand filter started out with a retention time of 11 minutes for the first 0.25 L of added waste. In comparison, the sand-pebble filter had a retention time of 6 minutes for the first 0.25 L. The last 0.5 L of added waste had a retention time of 40 minutes for the pure sand filter and 22 minutes for the pebble-sand filter. Since the influent volume was double for this last trial, the retention time for just 0.25 L may be estimated as 20 minutes for the pure sand filter and 11 minutes for the pebble-sand filter, or about twice as much as the retention time for the first run.

Phase II: Initial Evaluation of New additives

Figures 7-10 show a first attempt to develop a methodology for detection of garlic paste traces. Depicted is the absorbance for dilutions of garlic paste in visible light spectrophotometry.

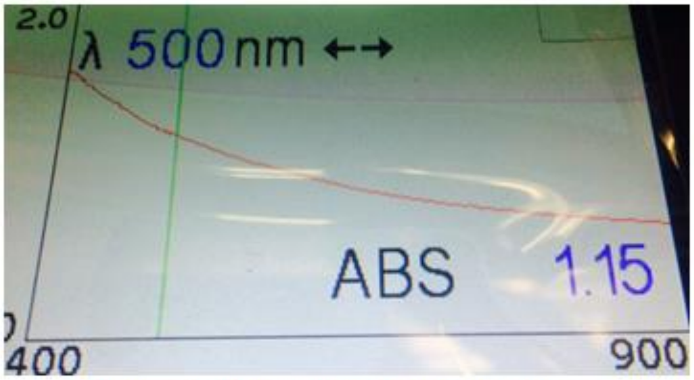


Figure 7: Absorbance of undiluted garlic paste.

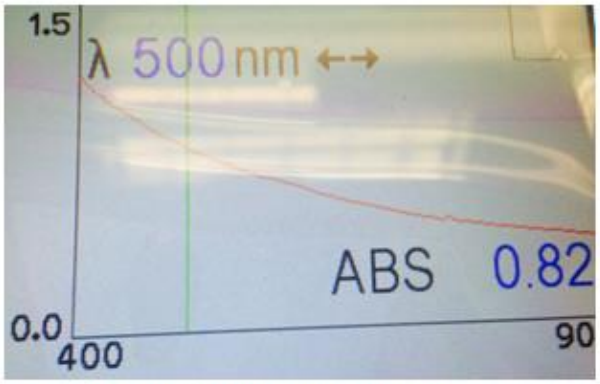


Figure 8: Absorbance of garlic paste diluted in a 2:1 ratio of garlic paste to water.

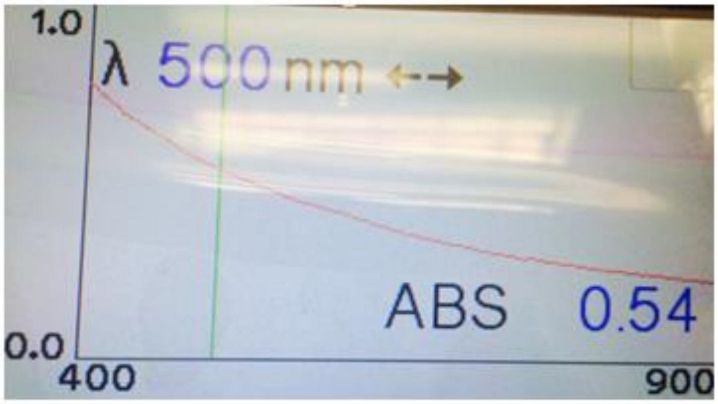


Figure 9: Absorbance of garlic paste diluted in a 1:1 ratio of garlic paste to water.

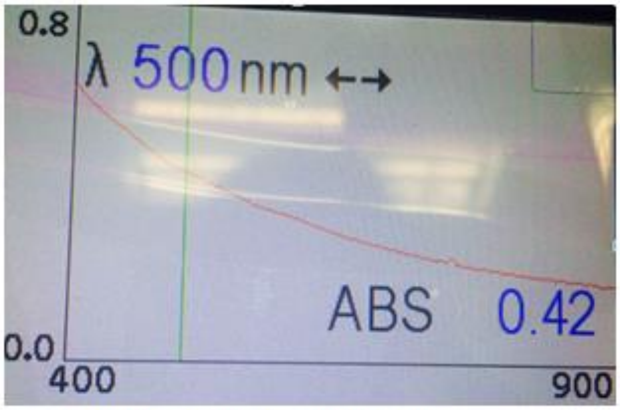


Figure 10: Absorbance of garlic paste diluted in a 1:2 ratio of garlic paste to water.

No clear peaks can be seen in the visible light absorbance curves for garlic paste. This suggests that visible light spectrophotometry may not be the best option for determination of garlic paste in effluent.

The author has also done initial measurements for the canola oil trials. Though the oil was initially distributed evenly throughout the second generation reactor, by the end of the first week, the upper cross section had 15% oil by volume, while the lower cross section had over 40% oil by volume, showing that oil clearly flowed down quite quickly.

Discussion and Analysis

It is observed that the spike in bacteria colony count in the effluent occurred later for the sand-pebble filter than for the pure sand filter. It can therefore be concluded from these data that the breakthrough of bacteria was measurably delayed when pebbles were added. This longer efficacy of the sand-pebble combination filter is most likely due to in part to the more porous nature of pebbles. Porosity refers to the ability of a substance to retain liquid. A pebble of diameter 10mm - 60mm typically has a porosity value of 0.4, higher than a grain of sand’s porosity value of 0.3 [16]. While sand grain clusters are themselves able to trap bacteria, mixing in pebbles creates “pockets” in the filter that can hold onto contaminated water and keep the sand part of the filter cleaner.

The data presented here has important and interesting implications in the context of the Sulabh International toilet systems. As noted previously, Sulabh systems are able to effectively compost feces into usable fertilizer. These are also able to filter out at least some of the bacteria in the output fluids. However, the data suggests that these are at high risk of eventual breakthrough – i.e. dangerous bacteria leaking into surrounding grounds and eventually making its way into the drinking water supplies, particularly when the groundwater tables are shallow. Since there are only 61 toilets currently installed in the target village, some bacterial output from the filters may not show a great increase in groundwater contamination. But, as three or four hundred more systems are installed in the tight living conditions of the village, higher concentration of bacteria getting through the filters may eventually become a major problem.

Furthermore, although by no means definitive, this study also strongly suggests that the incorporation of sand-pebble filtration can help make the toilets up to 83% more effective, at least during moderate usage, which makes the continued installation of toilets more feasible. This conclusion is based on the fact that 83% more volume was able to be passed through the sand-pebble filter before breakthrough occurred. Additionally, in the last trial in which bacteria strength could be meaningfully counted and compared, the sand-pebble filter let through only 5% of the bacteria that the pure sand filter allowed to pass into effluent. In real-life conditions, liquids travel horizontally through the filter, meaning a typically longer retention time and more thorough filtration.

As noted, the sand-pebble filter shows eventual breakthrough and the effluent in later runs contains high coliform counts (figure 4 and 5). However, runs were performed in rapid succession, with little time in between. Mapping this back to village conditions, 7 to 12 villagers will most likely not use the toilet in a row. This means the filter will have some recovery time in between runs. While this recovery time needs to be better characterized in future work, this idea coupled with the clear early advantage demonstrated by the sand-pebble filter shows a strong potential for in-field improvement. [14]. The coupling of these facts suggests that it is highly likely that the exhibited advantage of the sand-pebble filters will contribute to an increased filter life (nearly double at best), higher efficacy, and a better chance of filter recovery.

The shorter retention time for the sand-pebble filter could also be useful as it may allow more than one or two families to share a toilet. By removing the liquids from the waste holding chamber quicker, the sand-pebble filter makes room for additional waste. However, as more waste runs through the filter and more bacteria and other particles get stuck in the filter, retention time increases, as observed in the trials performed. This increase will have to be taken into account and further studied in order to determine how many more families each toilet with a sand-pebble filter can support.

It may be noted that other studies have been done on using pebbles to reduce water turbidity [16]. The study presented here, however, is different in that it quantifies the effects of pebbles on fecal coliform filtration, which can be applied to improving sanitation through effective human waste treatment.

The use of additives like various oils and garlic paste is still in the beginning phase. These materials are useful because instead of simply trapping bacteria, these have antibacterial properties that can eliminate part of the added bacteria population, which should help increase filter longevity. Construction and characterization of the second generation reactors and determination of methodology provides a strong starting point. However, the absorbance curves presented (figures 7-10) demonstrate that visible spectrophotometry is not an effective option to measure garlic paste concentration. Other studies have used UV spectrophotometry with wavelengths 10-380 nm successfully; availability of this option is being explored [24]. Other options include reacting either allicin or adjoene with other compounds and measuring the product concentration. This needs to be looked into further, but previous literature suggests that thiol-sulfate exchange reactions may be promising because of the sulfur groups present in both allicin and adjoene.

The canola oil trials demonstrate that liquid oil rapidly sinks to the bottom of the filter bed. This means that effluent exiting near the top of the filter will potentially still be ripe with pathogens by the time it enters the soil and water sources.

In the future, the author plans on using different “slow-release” mechanisms to prevent the influx of oil near the bottom of the filter. These mechanisms will include shelled objects or seeds such as turmeric, peanut shells, and grape seeds that will initially be soaked in and absorb liquid oil. When placed in the filter bed, due to the pressure produced by surrounding sand and outgoing effluent, these objects will perhaps slowly release the oil, so that it does not immediately pool at the bottom, and filtration efficacy is maintained throughout the filter.

Working with Sulabh International, the RNS Foundation (a charity locally based in Payagpur, North India), and the local Village Council, the author has obtained permission to add researched materials to future toilet installations. Based on the current and future efficacy data, the next round of installations of toilets in the target village in India will include filters with some combination of the researched materials. In order to measure the efficacy of these modified filters in real-life, soil samples will be collected and analyzed for fecal coliform contamination right after installation and then three months, six months, and one year after installation. Additional surveys of stratified samples of villagers will also be conducted regarding stomach and intestinal health.

After India, the long term goal of this project is to bring practical sanitation to rural regions around the world (see Table 1). The availability of materials in individual regions will be taken into account. Some natural materials like small pebbles are available in many rural villages. But, other materials, such as grape-seed extract, are more region-specific. While grapes are abundant in the villages of northeast India and in China, this is not the case for countries like Pakistan that also need safer sanitation [20]. In addition, as discussed in the introduction, different enteric pathogens vary based on region and environmental conditions. Thus, the goal is to develop different filters for different regions to account for material availability and climate variations.

Conclusions

Although this research is still in its infancy, a number of interesting conclusions may already be drawn based on the body of the completed work. These include:

1. The 0.15 m SSF filters currently used in the Sulabh 2-pit toilet design have a strong risk of failure in the form of pathogens passing into the soil and perhaps entering water supplies.
2. Pebbles were used as the first additive to enhance SSF efficacy and immediately proved to be a very promising addition. SSF efficacy was improved by approximately 83%; this advantage was demonstrated in all replicates. Therefore, it can be concluded that attempts to improve filtration using readily available natural substrates has much potential.
3. For liquid substrates such as oils and pastes, the downwards accumulation in the vertical SSF filter layer is a definite concern. Though these antimicrobials are promising additives to the SSF filter, future designs incorporating such substances need to address this concern.

In summary, incorporating additives into the SSF filters, coupled with Sulabh International 2-pit system's already existing cost and solid management advantages, make this design a very strong option for improved human excreta management around the world.

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