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Martina L. Houmann

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Constructed From Local Materials

Martina L. Houmann

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Research Advisor: Dr Ann Foster

Introduction

Safe drinking water is something that many people in industrialized nations take for granted; however, in developing countries thousands of people die for lack of clean drinking water and diarrheal diseases are epidemic in these regions. The World Health Organization (WHO) and United Nations Children's Fund (UNICEF) estimate that 1.5 million children worldwide die annually because of diarrhea and water-related disease, and that nearly one billion people lack safe drinking water (UNICEF, 2009). In addition, many of those that survive prolonged childhood diarrhea are found to have impaired physical fitness and are more likely to develop mental disabilities later in life (Guerrant et al. 1999).

Several water purification devices have been implemented by health organizations with varying degrees of success (Burch and Tomas, 1998). Many of the purification devices are for large-scale community water purification (Montgomery and Elimelech, 2007). Although it is important to provide water to as many people as possible, large water treatment facilities are complex, and often require maintenance by skilled personnel; something that is not always available in rural communities (Ochieng et al, 2004). Other difficulties occur when corruption in the local government halts community water purification (Hokanson et al, 2007). If problems occur with the infrastructure of the purification method in developing countries, it is difficult to obtain replacement parts, causing the device to be unusable.

Smaller scale water purification devices have also been well studied. Point-of-Use treatments are short-term water purification methods that allow people to purify their water just before drinking. The most common method of small-scale purification is boiling water. Boiling water has been a method that has been implemented for centuries. Although boiling does destroy *Escherichia coli* and other bacteria and protozoan cysts that can cause diarrhea, boiling

frequently requires large amounts of fuel, which is either lacking or takes a toll on the environment (Clasen et al, 2008). Wood collection is another concern for many women living in areas subjected to civil unrest. Many of these areas are unsafe for women and children to venture; yet, with the decline of sources of wood for boiling, the women and children are subjected to physical danger while searching for fuel.

Another type of Point-of-Use water purification is the use of a chlorine solution to decontaminate water. Chlorine water purification improves water quality by killing bacteria (Arnold and Colford 2007). Chlorination also has the added benefit of leaving a residue that can prevent recontamination. However, chlorination has its downsides in that chlorination is not effective in inactivating protozoan cysts and the chlorine taste may be unpleasant (Burch and Thomas 1998; Gadgil, 1998; Shannon et al. 2008). The chlorine also has a limited shelf life (Gadgil, 1998). Many countries do not have the economic means to manufacture chlorine, making this process of purification less sustainable than other methods.

Another form of water filtration is a slow sand water filter (SSF). The SSFs are cost effective and relatively simple to use (Burch and Thomas, 1998). One type of SSF is the biosand filter, which requires a *schmutzdecke*, a biological layer of algae that filters the organic molecules from the contaminated water. Below the *schmutzdecke,* the other sand layers remove the bacterial impurities (Logsdon, et al. 2002). Although the algae layer removes organic waste from the water, it will retain the contaminants unless it is regularly cleaned through agitation (Stauber et al. 2006). Another drawback for the biosand filter method is that if the *schmutzdecke* is not completely formed, the filter is not shown as effective (Stauber et al. 2006). While the *schumutzdecke* is reforming, the villagers must either have multiple sand filters available or use other means to keep their water clean (Burch and Thomas, 1998).

The goal of this experiment is to construct a filter that will be easy to use and composed of items that are readily available to villagers in developing countries. This filter model should be easily assembled in short notice, with materials that can be promptly replaced if they are not working correctly.

Materials and Methods:

Filter

Two two-foot long, two-inch diameter polyvinyl chloride (PVC) pipes were obtained from a local hardware store to be the column for the filter. The two pipes were joined by a coupler and sealed with household adhesive sealant (100% silicone) to prevent leakage. Fifty grams of finely ground, activated charcoal were poured into the column, followed by 500 grams of sand both of which were used as filtration mediums. To prevent the charcoal from falling through the pipe, a septum was made by cutting a small piece of balsa wood to the size of the PVC pipe with a knife and drilling holes in it to allow for drainage (see Figure 1). Two sizes of holes were used: larger, 4 mm holes and smaller, 2 mm holes. These holes were 10 mm apart with alternating rows of larger and smaller holes. Since the grains of charcoal were fine enough to slip through the holes of the septum, filter paper was cut to the size of the septum and placed over the septum before the filter was pieced together. The balsa wood septum and filter paper fit securely inside a coupler (see Figure 2) secured by silicone and the complex was then placed on the end of the PVC pipe (see Figure 3).

Figure 1. *Balsa septum*

Figure 2. *Balsa septum in PVC coupler*

Figure 3. *Column*

Bacterial Load in Column

To obtain the amount of bacteria colony forming units (CFUs) prevalent in the column itself, tests were performed by pouring tap water into the column and collecting a sample of water after it had permeated the sand-charcoal medium. All colonies that formed on agar plates after filtration were assumed to be flushed from the column. Serial dilutions were performed on the sample water according to Leboffe & Pierce's experimental design (2010) 0.5 ml of each

dilution and the source tap water sample were then plated on nutrient agar plates. The plates were examined after an overnight incubation and the coliform colonies were counted. Plates that contained more than 300 colonies and less than 15 colonies were not considered statistically viable and therefore were recorded as too many to count (TMTC) and too few to count (TFTC) respectively. Colonies were counted from the tests by using a colony counter light to illuminate and magnify the plates, and a colony counter pen to tally the number of coliform colonies.

Bacterial Growth

A growth curve was needed to determine the number of *E. coli* CFU/ml every hour after initially inoculating a flask of nutrient broth. To obtain the growth curve, *E. coli* was inoculated into 50 ml of nutrient broth and allowed to grow for several hours on an incubator-shaker at 37.4 °C. The absorbance of the *E. coli* broth was checked every hour by using a Spectronic 20 Spectrophotometer with the wavelength set at 440 nm. When the *E. coli* inoculation broth reached an absorbance of 0.3, a 1% inoculum, 2.5 ml, was placed into a flask containing 250 ml of sterile nutrient broth. If the absorbance was slightly over 0.3, the culture was diluted with nutrient broth until the absorbance was exactly 0.3 and 2.5 ml was then placed into the 250 ml broth with the proper dilution. The 250 ml growth flask was then placed on the incubator-shaker and tested for absorbance every hour after an initial incubation period of 2.5-3 hours. Serial dilutions were also completed along with each absorbance test. The plates were placed in an incubator overnight and counted to determine the maximum growth curve for the *E. coli*.
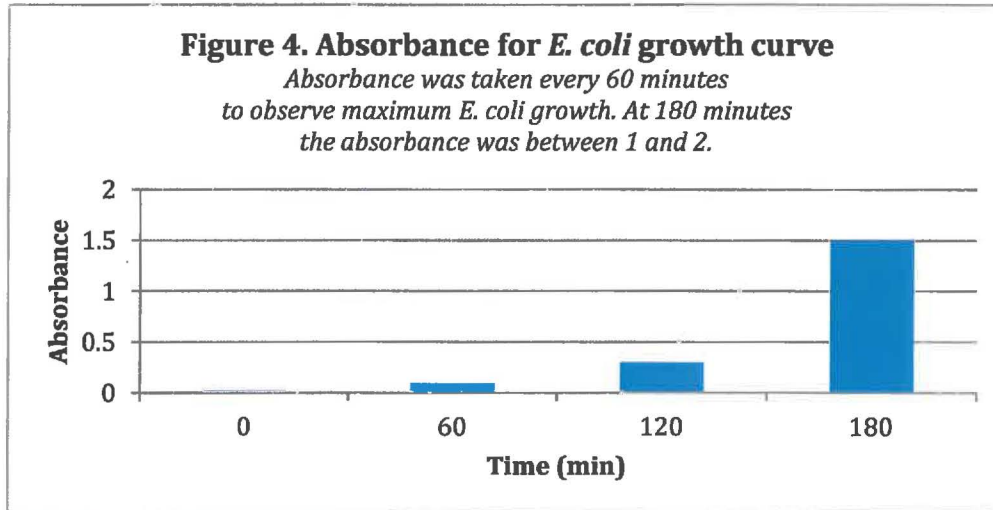
Column Testing

After obtaining the growth curve for *E. coli*, the maximum growth concentration was used to run through the column. To do this, *E. coli* was grown as stated above and once the absorbance of the 250 ml growth flask reached 0.3 the *E. coli* was washed by centrifugation and

and 95% ethanol, the filter paper was removed, and the septum was left to dry before the next use.

Results:

When testing the column with pure tap water, the column water NA plates 10^0 to 10^{-3} had bacterial growth. The maximum contaminant level goal of coliforms, including *E. coli*, for drinking water are 0 mg/L according to the United States Environmental Protection Agency (EPA 2012); therefore, the growth on the NA is considered to come from the column. The colonies were not counted since there was a significant amount of smearing from motile colonies on the plate. Dilution samples from 10^{-4} through 10^{-8} had TFTC. No EMB plates were tested because the tap water was expected to contain fewer than 1 *E. coli* CFU/100 ml and the sand was not exposed to fecal contamination; therefore, no data was gathered concerning whether or not the column had an *E. coli* presence. No significant bacterial contamination was observed for the source tap water.

When analyzing the growth curve of the *E. coli*, it was discovered that the *E. coli* had the highest replication rate between four to five hours after the initial inoculation into the 250 ml growth flask. Figure 4 shows the absorbance levels over the collection time. The absorbance level corresponded with the amount of growth on the Nutrient Agar plates.

Figure 4. Absorbance for *E. coli* growth curve
*Absorbance was taken every 60 minutes
to observe maximum E. coli growth. At 180 minutes
the absorbance was between 1 and 2.*

Samples taken from the column following the washed *E. coli* solution did not show any growth, either on the EMB or NA plates, even though the solution contained 5.9×10^5 CFU/ml before it was poured into the column. The absorbencies of the samples after each fifteen-minute period were 0.02, 0.01, 0.00, and 0.00 respectively.

The unwashed *E. coli* suspended in nutrient broth was placed through the column and samples were removed every 15 minutes for plating. The NA and EMB plates for the unwashed *E. coli* showed similar results to the washed *E. coli*; TFTC from 10^{-3} to 10^{-6}. Less diluted samples, 10^{-3} to 10^{-6}, were taken and then the unwashed *E. coli* sample, 10^{-5} to 10^{-7}, was taken in order to determine whether the washed *E. coli* was simply too diluted to detect. The *E. coli* solution that was poured into the column was a cloudy tan color, but once it came through the column, the liquid appeared clear. The absorbance of the broth before it was placed in the column was 0.85, which corresponds to approximately 6.4×10^5 CFU/ml and should have been at its optimal growth curve. Absorbance for the samples was zero.

As with the *E. coli* tests, the first creek water test samples were gathered every fifteen minutes. The first creek water test differed from the *E. coli* tests as follows: the unfiltered water was filled to the top of the column as opposed to only 250 ml, and the filtered samples were not

serially diluted but were plated directly onto the EMB and NA plates. A large amount of growth

was recorded and was, in many cases, TMTC. Growth was recorded for both the NA and EMB

plates. On the EMB plates, growth included colonies that were clear, clear with a black center,

and those with the characteristic green sheen of *E. coli*. The green was not prevalent in the

unfiltered creek water sample.

To negate the possibility that the water pressure might have pushed *E. coli* through the

column, the second creek water test was conducted with 500 ml of contaminated water, only

slightly more than what was loaded with the *E. coli* tests. Dilutions 10^{-3} and 10^{-4} were all TFTC

and 10^{-2} was mostly TFTC with the exception of two plates, one plate of NA and one of EMB.

Dilutions 10^{0} and 10^{-1} had significant growth (see Figure 5). Some of the colonies were too

clustered or too smeared to get an accurate counting, however. In both of the Wilkerson Branch

tests, large coliform colonies were observed on the source plates, sometimes covering most of

the plate. None of these coliforms (Figure 6) appeared with the same large circumference as in

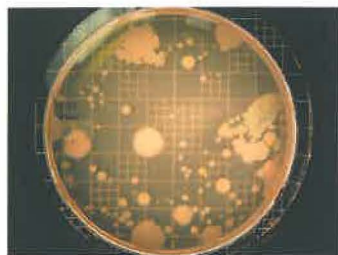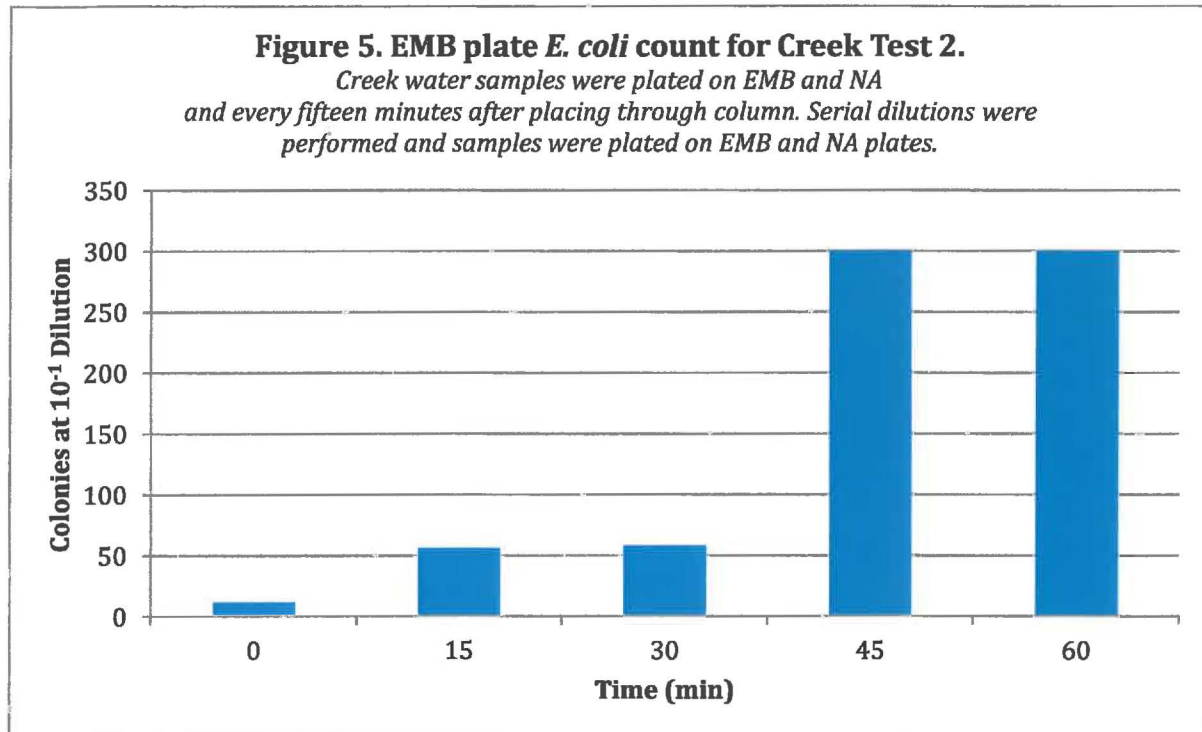the source water plates (Figure 7).

Figure 5. EMB plate *E. coli* count for Creek Test 2.

*Creek water samples were plated on EMB and NA
and every fifteen minutes after placing through column. Serial dilutions were
performed and samples were plated on EMB and NA plates.*

Figure 6. *Undiluted growth from Wilkerson Branch in nutrient agar plates*
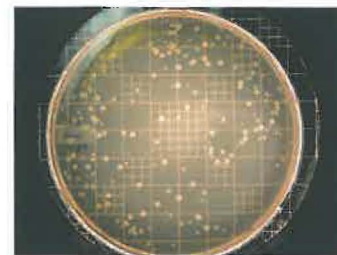

Figure 7. *Undiluted sample growth in nutrient agar after 30 minutes*

Discussion and Conclusion:

There are several variables that must be considered when discussing the data. One variable regards the bacterial growth in the filtered water. Based on the tap water test, there was shown to be growth after the tap water was placed through the filter. This growth may be due to unsterilized column contents. The column was purposefully left unsterilized to imitate as closely

as possible the conditions and resources of developing countries. Villagers who have no access to potable drinking water certainly would not have access to an autoclave. Therefore, sterilizing sand, charcoal, or the pipe would be implausible. However, this experiment did not explore the possibilities of sanitizing the sand through UV exposure, or sunshine, which may facilitate more satisfactory results. Other experiments may be done to determine whether different sand samples have different levels of contamination.

Future research may also determine whether contaminants may be flushed out after multiple uses of the filter. For the purpose of consistency of the experiment, the sand and charcoal was changed after every sample test; however, the column may filter better after it has been flushed out over time. With more uses, the charcoal and sand may become more compact, possibly influencing the efficiency of the water filter.

Another variable to consider is the level of sand and charcoal. Since this was a pioneer project, there were no models to delineate the proper ratio of sand to charcoal. Other tests should be performed to determine which sand-charcoal ratio has the highest efficiency. Different ratios of sand and charcoal could be tested to see what ratio might remove enough organic material as well as filter out bacteria. Also, stream sedimentation could have negatively impacted the charcoal and sand's ability to filter *E. coli*. More sand may be needed as a "roughing filter" to remove the debris that occurs naturally in stream water. Another consideration is whether layering sand and charcoal will make a difference in purification.

The filter did not seem to remove *E. coli* from the creek water; however, there may have been other bacterial or parasitic organisms that were removed by the sand-charcoal filtration. As stated previously, certain large coliforms on the unfiltered water plates were not observed on the filtered water plates. Other things such as helminthes or cysts may have been removed from the

any other non-toxic sticky material. If a wooden septum is unavailable, cheesecloth may be substituted, clamped tightly between the coupler and the pipe.

Very fine, activated charcoal was used for the test column, which also might be difficult to obtain in developing countries. For the purposes of the experiment, larger, inactivated charcoal was sought after, but was not able to be acquired. It was assumed, however, that untreated cooking charcoal might be the functional equivalent of the activated charcoal for the purpose of purifying water. The cooking charcoal could be ground by the villagers in a mortar and pestle to obtain the desired diameter of charcoal for the filter. Since hand ground charcoal would probably not be as fine as the charcoal used for the experiment, it would be less likely to sift through the pores of the septum at a high rate, negating the need for filter paper. However, this also might impede the efficiency of the filter. Research should be done in order to determine the optimal materials that should be used, and also to determine whether coarser, inactivated charcoal may be substituted for activated charcoal.

This experiment was a pioneer project to construct and test a water filter that would be efficient and effective. The time limitations and small scale of this study enhanced the difficulty of obtaining encompassing results. Even with the primary evidence that has been obtained, it is difficult to universalize the results without many more trials on each test. Other tests should also be performed, including the following: UV-exposure to charcoal and sand, changing the charcoal-sand concentration, measuring the degree of charcoal-sand compaction, and testing effectiveness of filtration with parasites. With more time and resources, a more comprehensive study should be performed on the column. More conclusive evidence should be obtained before accepting or rejecting the filter.

Although the tests on the column had both positive and negative results, it is advantageous to continue research on this project. Thousands of people are dying every day because of unsanitary drinking water. Tragically, many of the water filtration techniques available in developing countries are retained in the more affluent areas, leaving the villagers without access to potable drinking water. If they could use a simple, efficient, effective water filtration device, many more people would have the opportunity to obtain cleaner drinking water, decreasing the amount of deaths from contaminated water.

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