May 10, 2013
Engineering for Developing Communities
Prof. Patricia Culligan
Prof. Stephen Forbes

Alexander Lopez

Nicole Olaes

Otis Poisson

Ceramic Water Filters

PROJECT SUMMARY

Client

Edward Eleazar

Group Members

Alexander Lopez, Nicole Olaes, Otis Poisson

Location

Kampala, Uganda

Summary of Project Goals

Figure 1 - Clay Pot Water Filters (Source: Potters for Peace)

Water quality is one of the most widespread and important of global development issues. It is estimated that 780 million people worldwide lack access to clean water – about one in every nine people.[1] In recognition of this need for clean water, for the purposes of drinking, cooking, and other daily sanitation and hygiene services, many organizations have started programs with the intention of bringing safe, potable water to developing communities in a sustainable way, where the water can be continuously generated by members of the communities themselves. These methods are widely varied and can take the form of improved water sources, such as protected groundwater wells, or treatment options such as the addition of chlorine or other disinfesting chemicals. Still another method is to filter contaminants out of the water supply by exclusion, by passing the water through a porous medium. This is the essential concept behind clay water filters. The implementation of clay water filters has seen great effectiveness in certain scenarios, but research in the area is often disorganized and is sometimes missing third-party verification. This is demonstrated perfectly by one of the questions which our team entered this project with the goal of answering: from filter distribution projects led by the Cambodian government, there was uncertainty even as to whether clay water filters needed to be cured for a certain length of time after firing in order to retain their effectiveness. Ultimately, the goal was not only to answer this question but to be able to recommend a type of clay water filter for sale and distribution in Uganda, based on analysis of two models, along with delivery of qualifications regarding the effectiveness of each.

Proposed Solution

Our team sought to determine whether clay water filters are a viable solution for clean water problems in developing countries by first resolving the question of curing times through conversation with experts who have experience in the fabrication of clay filters. Second, our team performed independent research on the cleansing efficiencies of *Escherichia coli* on two types of clay water filters, a clay pot model used by the organization Potters for Peace, and the smaller "candle" model produced by iCATIS – more background on these organizations follows in the main body of this report. The testing process involved obtaining prototypes of each filter for laboratory testing and conducting background research on the advantages and disadvantages of each. Our team considered each filter holistically, evaluating not only *E. coli* removal rates but also flow rates, size, ease of use, maintenance, and additional pertinent changes in water chemistry caused by the filter media, such as the presence of arsenic and lead.

Conclusions and Recommendations

The quantitative tests (metal and *E. coli*) showed that both the clay pot and candle filter produce potable water from contaminated water, with low levels of arsenic and fecal coliforms in accordance with WHO standards. In order to sustain high water filtration quality, both the ceramic pot and candle should be cleaned regularly (exactly when depends upon the amount of contamination in water and frequency of use). Flow rate testing showed that the clay pot filter produced water at a speed almost twice as fast as the candle filter. A recommendation to improve the flow rate of the candle filter would be to design the device such that one could scrub the ceramic piece, removing particles hindering water movement. Volumetrically, the candle filter was able to hold much more than the clay pot. Also, the clay pot came with a collection bucket that did not seem big enough, risking recontamination as the filtered water was in direct contact with the bottom of the clay pot. Both filters were fairly user-friendly, easy to understand and operate, but fragile. The base of the candle filter broke in transit and the spigot of the clay pot filter broke after a couple days, leaking filtered water everywhere. Although they were easily maintained, the slow flow rates (especially for the candle filter) may affect their practicality in the household. Recommendations for our client to acknowledge our testing results and observations include designing for maximum flow rates, maintaining high water quality, and increasing robustness of the filter. Design recommendations for the filters and suggestions for project continuance are also detailed later in the report.

REPORT BODY

Introduction

The original conception for the project began as an answer to a couple different, smaller questions regarding household water treatment methods in developing communities all over the world. One of these questions came from Cambodia. In the past, non-governmental organization (NGOs) in Cambodia had implemented widespread bio-slow sand filters (BSSFs) in different communities as one method of point-of-use water treatment. However, the Cambodian government tried to replace BSSFs with clay pot filters for several reasons, including the difficulty of maintenance of BSSFs, which requires maintaining a biologically active layer and certain conditions.[2] Before such a major change could take place, one issue that needed to be addressed concerned reports that ceramic water filters needed to be dried and cured for a one-year period following their molding and firing in a kiln. If this report turned out to be true, families could potentially be vulnerable to contaminated water during the one-year curing time.

At the same time, an organization called CATIS-Mexico, an affiliate of Colorado-based iCATIS (International Centers for Appropriate Technology and Indigenous Sustainability), had developed a ceramic water filter of their own design, nicknamed the “candle” filter. Our team first learned that the candle filter claimed to offer no necessary curing time, but that iCATIS was seeking independent evaluation of their filter model.

Finally, our team was familiar with the development and entrepreneurial efforts of Edward Eleazar, who is interested in personally manufacturing and selling ceramic water filters to families in need from his home in Kampala, the capital city of Uganda. Mr. Eleazar is interested in ensuring the sustainability of his water filter business model by being knowledgeable about the most relevant type of water filter to distribute, and is wary of “one type fits all" models, which have failed when they have been implemented in developing countries in the past. Mr. Eleazar has assumed the position of our team's client, and all of our research stemming from the above-described paths has culminated to develop as much helpful information as we could to serve Mr. Eleazar, iCATIS, and CATIS-Mexico.

Client

Edward Eleazar has had a long-standing relationship with Columbia University, its students, and with Stephen Forbes, a faculty member and mentor for Columbia's students. Mr. Eleazar, apart from his own growing business to produce ceramic water filters, is also an employee of an NGO named Pilgrim, which has offices both in the United States and in Uganda. Pilgrim is a faith-rooted organization which was originally founded in 2001 to aid refugees living in internally-displaced persons camps in Uganda, but has since expanded its services to include efforts in agriculture, education, public health and combating malaria, and relief.[3] Mr. Eleazar first interacted with Columbia's students through an intersection of Pilgrim's agricultural movement and Columbia's student chapter of Engineers Without Borders – Uganda, for which Pilgrim is the partner organization.

Mr. Eleazar has much experience as a development worker in Uganda. Formerly a pastor, he has served with Pilgrim in multiple roles including Program Manager and Science Researcher on projects implementing multi-functional platforms (diesel engines with agricultural processing attachments) in farming cooperatives across the Teso sub-region of Uganda. Mr. Eleazar has more recently begun his work relevant to our team's goals of researching and analyzing different ceramic water filters by way of a startup business with personal investments. Mr. Eleazar has constructed a wood-burning kiln near his home in Kampala, Uganda and is already making bricks and clay tiles, which serve a use as preliminary testing for the kiln and also can be sold to help fund the costs involved. Mr. Eleazar's kiln is designed to be multi-purposed and capable of producing different ceramic products in the long-term.

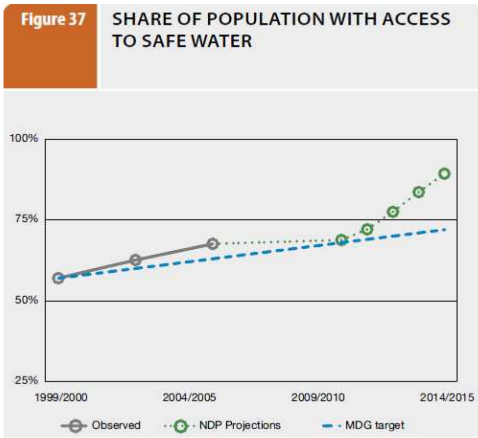
While not fulfilling the role of "client" per se, the staff of CATIS-Mexico and iCATIS, most notably Dylan Terrell and Dr. Mark Reiner, has been of particular help to our team and must be given special mention. Both Mr. Terrell and Dr. Reiner have been central in helping to provide us not only with a prototype candle filter to perform testing, but with advice and resources pertaining to the design, manufacturing, and best management practices of ceramic water filters. Mr. Terrell is the on-ground Executive Director of CATIS-Mexico. He has years of experience working with grassroots organizations in low-income and developing communities in the United States, Argentina, Peru, Guatemala, and Mexico. Dr. Reiner is a registered professional engineer on iCATIS' board of directors who has experience in the areas of sustainable urban infrastructure and low-cost housing design. He has also served as Projects Director for Engineers Without Borders – USA while working in Rwanda, and has been an adjunct faculty member at the University of Colorado at Denver.

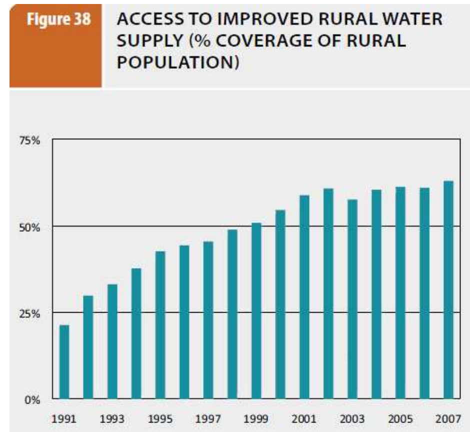
Project Location and Context

Figure 2 - Map of Uganda (Source: Uganda Bureau of Statistics)

Hand-in-hand with the home of our client, Edward Eleazar, our project takes place in Uganda, but is purposed to help fulfill the needs of developing communities across the world, including those in Mexico, which is the aim of CATIS-Mexico, and potentially Cambodia and anywhere there is a need for point-of-use water purification on a household level. For the purposes of this narrative, however, the project's regional context will be established as developing communities in Uganda, which Mr. Eleazar aims to serve.

Of 19 available Millennium Development Goal targets, Uganda is on track to achieve only 7 of them, as of 2010.[4] Within MDG Goal 7 alone, the purpose of which is to ensure environmental sustainability, Uganda is currently on track to achieve one of them, Target 7.C: to halve, by 2015, the proportion of people without sustainable access to safe drinking water and basic sanitation. Surprisingly, this target is also the focus and intended application of our project. Target 7.C is measured by two indicators, the proportion of population using an improved drinking source and the proportion of population using an improved sanitation facility. The share of individuals in Uganda with access to safe drinking water has increased from 57% in 1999-2000 to 68% in 2005-2006. Thus, the government has been on track to meet its own target of 89% access in 2014-2015, which is considered to be a much more ambitious target than the implied MDG target (see Figure 3). While the percentage of access to safe drinking water is still considerably lower in Uganda's rural areas relative to urban areas, the progress made in rural areas has been the largest. Access to improved rural water supply has increased from only 21% in 1991 to 63% in 2007 (see Figure 4). Still, given these advancements, the lack of access to safe drinking water in many parts of Uganda has been personally witnessed by members of the team, and it is unquestionable that there remains much work to be done.





Figures 3 and 4 – Source: Uganda MDG Progress Report 2010

Problem Description

The spirit of the problem being addressed is the portion of the safe drinking water gap which remains to be filled. Taking motivation from different development organizations around the world, our team is looking to devise a method of treating water so that any water source can be used to collect water. The water can then be transported back to the home, put in a filter, and left to purify itself, ideally over the course of a few hours. This is one key difference between our team's approach and several other strategies: Mr. Eleazar and our team have chosen to focus on the use of ceramic water filters on the household level, for point-of-use applications (treatment which occurs directly at the user's final delivery source). This method has several advantages. It allows for a smaller, more sizeable, and more affordable system which can fit in a typical household; it encourages responsibility and maintenance of the filter system, as the owners are more clearly-defined.

Mr. Eleazar began his startup business with the intention of selling ceramic water filters to families in Uganda before our team began evaluating filter types. Therefore, our deliverables are aimed at serving his end, as his work is already well-established and has taken a clear direction. Our results primarily concern the evaluation of two separate types of water filter, both of which are described in more detail in the following section. Our results are intended to help Mr. Eleazar determine which type of filter, if any, is most appropriate to suit his own needs and the needs of the communities in which he is involved, a decision which can be based on our findings of both the filters' removal efficiencies and other properties, such as the user-experience derived from each filter.

As stated previously, we also set out in our project to respond to the question of curing times for clay water filters. While this had been a concern for filter distribution in both Cambodia and Uganda, Dr. Mark Reiner of iCATIS, an expert with experience in the design and use of clay water filters including the "candle" model, helped debunk this notion.[5] Thus, from conversation with an expert, our team is confident that the idea of a one-year period of curing time for clay filters is simply a rumor.

Project Goals

Project goals in particular focus on how the clay pot filter and candle filter are evaluated. This section first describes important features of both filters, and then describes the evaluation criteria.

We tested two types of ceramic water filters – the clay pot filter used by Potters for Peace (PFP) and the ceramic "candle" filter developed by iCATIS. Compared to other small-scale water filters, such as the bio-slow sand filter (BSSF), ceramic filters are reportedly more easily maintained and simpler to use; they may be easily transported at any point in their life-cycle; and they are known to filter contaminated water at similar levels of effectiveness to BSSFs in terms of flow rate and bacteria removal.

The PFP filter is a simple press-formed bucket made of terra-cotta clay and sawdust (other combustibles may also be used however, such as rice husks). The standard bucket dimensions are 11”x10” (width x depth) and a slight taper allows the filter to fit easily into a 5-gallon plastic or ceramic bucket that catches and holds filtered water. When in use, water should pass through the filter at the rate of about 1.5 to 2.5 liters per hour. Filter firing occurs at about 860 ºC (1580 ºF), during which time the combustible matter in the mixture burns out, leaving just the porous clay walls (of fine pore size). Each filter is then coated with colloidal silver, which acts as a bactericidal agent. About fifty filters may be produced each day at a production facility with three or four workers. The price of a filter, including its catchment receptacle, is generally between $15 to $25 and a replacement filter costs $4 to $6.[6] The Potters for Peace model encourages local production of water filters within a community, and so holistically includes implementation of a filter workshop, training on their fabrication, etc.

The candle filter developed by iCATIS was intended to be a smaller, more robust package than more traditional clay pot filters, such as the one used by Potters for Peace. The candle filter is claimed to have a similar filtration flow rate, of about 1 to 2 liters per hour, which should also be enough to provide enough drinking water to a family of about six. The mechanics of how filtering actually works with the candle filter is also similar to that of the clay pot filter. The candle filter should not, however, be discussed without mention of the MK Kiln, another development from iCATIS. Both the candle filter itself and the MK Kiln were designed by iCATIS’ Director of Research and Development, Dr. Robert Marquez. According to Dylan Terrell, the MK Kiln can reduce standard emissions from brick kilns by at least 80%, while also reducing fuel usage and burn time by 50%. Thus, the MK Kiln and candle filter are specially designed for use by CATIS-Mexico and meant to go hand-in-hand in order for the full potential of both systems to be taken advantage of. The kiln is attractive to the state, as it reduces emissions produced by the more widely-used open-air kilns, and it is also attractive to the manufacturers of the filters, as the need for less fuel greatly increases the profitability of producing and selling filters.[5]

In an effort to evaluate both models of filter on the bases of as many merits as possible, we researched multiple factors. These included effluent water quality, measuring the removal rates of *E. coli* and checking for the potential unintended additional of hazardous elements such as arsenic and lead, flow rates and how they can be optimized, necessary maintenance and how this affects the above factors, and general ease of use and what is required of a filter user to maintain a functioning filter, considered to be as important as any of the other above factors in terms of sustainable design.

Project Description and Outcomes

In order to conduct a comparative analysis of the candle and clay pot water filters, the respective devices were obtained and utilized for household practicality. The filter assessment includes three quantitative tests: flow rate, arsenic/lead, and *E. coli*.

Flow Rates

Unlike BSSFs, which can provide a large surface area of sand for water to flow through, the surface area of the ceramic pot and candle piece is limited and thus water flows through slower, producing less potable water per hour. Flow rates are an important factor determining whether the filter can provide enough water in a given amount of time for the whole household. In these tests, flow rates were obtained by filling both filters with tap water, waiting a specific time period, and measuring the amount of water that had been filtered during that time. At first, both filters were very slow, taking 3 or more hours to filter only 1 liter of water. However, after a number of liters are filtered through each, the flow rates increased, indicating a standard "breaking-in" period for each filter. In a developing community household setting, this could pose problems. If this was the first and only filter, families will need to obtain potable water elsewhere during the breaking-in period. Once the filters operate at optimum speeds, the candle filter produced around 0.6 L/hr and the clay pot filter 1 L/hr. The candle filter's ceramic piece has a much smaller surface area than the clay pot filter, resulting in the reduced flow rate. Another possible factor slowing the candle filter is the fact that the clay pot filter is easily cleaned but the candle filter's ceramic piece should not be removed from the device and thus was not cleaned. Scrubbing the surface of the clay removes particles that can greatly hinder flow rates; thus, the candle filter's flow rate could be increased if it were easier to scrub clean.

Arsenic Testing

Prolonged exposure to arsenic has been shown to cause cancer, and the most common route of exposure is food or beverage consumption. The WHO guidelines allow a maximum of 0.01 mg/L of arsenic in drinking water, which reduces risk levels and limits health effects, taking cumulative consumption under consideration.[7] Samples of unfiltered New York City tap water (as a control), filtered tap water from the clay pot, and filtered tap water from the candle filter were sent to the lab to test for arsenic, barium, copper, lead, manganese, silver, and zinc. The lab results of the tests were as follows:

Control

Element	on [mg/L]
Arsenic	<0.007
Barium	0.015
Copper	0.186
Lead	<0.003
Manganese	<0.007
Silver	<0.007
Zinc	0.054

Clay Pot

Element	on [mg/L]
Arsenic	<0.007
Barium	0.054
Copper	0.011
Lead	<0.003
Manganese	0.024
Silver	0.016
Zinc	0.023

Candle

Element	on [mg/L]
Arsenic	<0.007
Barium	0.06
Copper	<0.003
Lead	<0.003
Manganese	<0.007
Silver	0.024
Zinc	0.206

Table 1 – Control, Clay Pot, and Candle Samples Concentrations

The clay pot sample showed increases in barium, manganese, and silver with decreases in copper and zinc. The candle filter showed similar increases in barium and silver but an additional increase in zinc. This increase in zinc may be due to different tap water quality, as the control group was taken from the tap water going into the clay pot, though the quality should be around the same. The increase in silver may be due to leaching from the filter's colloidal silver additive, and the increase in barium may be due to barite, a common clay mineral. The decrease in copper may be due to clay pot absorption. All of the increases, however, were still at low levels and pose no health risks. The results indicate that the filters do not present significant arsenic or lead concerns.

E. coli Testing[8]

E. coli is a thermotolerant (fecal) coliform, whose reduction in drinking water can reduce risk of diarrheal disease. The experiments testing for fecal coliforms involved creating a contaminated batch of water (diluted to a specific concentration of *E. coli*), running the contaminated water through the filters, and using various tests to read the contamination results of filtered water. The two results-reading tests were the Idexx tray test and compartment bag test. Compartment bag tests involve putting water into a bag separated into 5 compartments. Results depend on how many compartments turn from yellow to blue, blue indicating a positive reading for *E. coli.* The compartments were different sizes: 56 mL, 30 mL, 10 mL, 3 mL, and 1 mL. Results were read from largest to smallest compartment, with a "1" indicating positive (turned blue) and "0" indicating negative (stayed yellow). The Pot In sample turned blue in the largest (56mL) compartment, so the result was "10000." According to the compartment bag test table, that indicates an MPN (most probable number) of 1.5 colony forming units (CFU) per 100 mL with a maximum (95% confidence level) of 7.81 MPN per 100 mL. The compartment bag tests turned out to be inconsistent, as the tested contaminated water (going into the pot and candle filters) only turned blue in one compartment for one bag and no compartments for the second bag. Therefore, although the filtered water resulted in all negative compartments, the fact that the contaminated water also tested negative skews the results.

Idexx tray tests feature multiple wells and the results depend on how many of these wells turn yellow or glow blue under UV lighting. The Idexx tray test proved fairly accurate, as the contaminated water showed different levels of positive readings. The results shown below indicate both filters proficiently filtered out mostly all of the *E. coli* from the contaminated water.

Risk Level	**Number of *E. coli* per 100 mL**
Conforms to WHO guidelines	<1
Low Risk	1 - 10
Intermediate Risk	10-100
High Risk	100-1000
Very High Risk	1000+

Table 2 – WHO Risk Level Classifications

Sample	**Number of *E. coli* per 100 mL**
10^{-9}	131.4
10^{-10}	20.3
10^{-11}	2
Pot In A	3
Pot In B	2
Candle In A	2

Candle In B	3.1
Pot Out A	< 1
Pot Out B	< 1
Candle Out A	< 1
Candle Out B	< 1

Table 3 – Idexx Results

Outcomes

From the flow rate results, the clay pot filter would provide the most potable water in the shortest amount of time. At optimum performance, the clay pot filter would produce 24 L per day. If the average person drank 2 L per day, one clay pot filter could hydrate 12 people or provide clean water for cooking or other uses. From the arsenic results, both filters produce water with safe levels of arsenic, lead, copper, and zinc. From the *E. coli* results, both samples of filtered water met the WHO drinking water quality guidelines and thus successfully improved the bacteriological quality of the contaminated water enough to potentially provide safe drinking water to a household. Recontamination of filtered water may occur throughout the lifetime of the filter, and maintenance of not only the filter element but also the receptacle and spigot can also affect the water quality.

Project Timeline and Cost Estimate

Week	Activities
1: March 3-9	Research and Plan; Present SOW
2: Mar. 10-16	Contact filter distributors
3: Mar. 17-23	Purchase filters
4: Mar. 24-30	Filters in transit
5: Mar. 31-April 6	Filters mailed to Columbia
6: April 7-13	Build base for candle filter
7: April 14-20	Flow rate testing
8: April 21-27	Running water through filters
9: April 28-May 4	Water quality testing
10: May 4-11	Finalize report and presentation

Table 4 – Project Schedule

Our project timeline as implemented varied greatly from our planned timeline because of the unforeseen difficulty of finding ceramic filters for purchase and delivery. With only 10 weeks to conduct our whole project, finally obtaining the filters on the 5th week left little time for testing and observing the user experience. Also, during transportation of the candle filter the base broke, requiring us to build a new base before completing any testing. In regard to cost, the candle filter was a prototype provided free of charge (besides shipping and handling) and the Potters for Peace clay pot filter was $114. Obviously, the clay pot filter would have to be sold at lower costs in developing countries for any of the families to be able to afford it. The candle filter may or may not cost less than the clay pot filter; it is not yet widely distributed.

Operation, Maintenance, and Sustainability

Some aspects of operation, maintenance and sustainability are similar for both the clay pot filter and the ceramic candle filter. These matters will be discussed both individually for each filter and in a general sense. Looking first at the operation of each filter, dissimilar from BSSFs, ceramic filters are meant to contain nothing but the water that is filtering through them. They are thus quite portable and easy to use. In using the filters, after pouring water into the top of the filter it will pass through the fine pores of the ceramic, emerging into a catchment tank below, which should be equipped with a functioning nozzle or tap so as to prevent the filtered water from being re-contaminated before use. Both filters are meant to be delivered to the user with a post-filter holding tank included (5 L for clay pot and 12 L for the candle).

The flow rate (water passing through ceramic) of both the clay pot filter and the candle filter is rated by the supplying organizations at about 1 to 2 L per hour as long as a significant head of pressure above the filter is maintained (i.e. the holding zone of unfiltered water remains relatively full). The clay pot filter does not hold nearly as much unfiltered water as the ceramic filter, which consists of a 19 L plastic carboy with the filter sealed into the neck of the jug.

Maintenance of each filter requires gentle scrubbing of the ceramic exterior on a periodic basis or if the flow rate becomes too slow, a sign of pore clogging. The clay pot filter is very easy to scrub, as the entire filter (the pot) is removable and therefore easily accessible. The candle filter, on the other hand, is sealed into place and is more difficult to access. While we did not test either filter for long enough, nor did we put any turbid water through, to see how the filter may become clogged or less efficient in terms of flow rate or bacteria removal, we did notice the difference that an initial scrubbing made. The clay pot filter was scrubbed with water upon arrival while the candle filter was not scrubbed. This may have had an effect on the flow rates we recorded (significantly slower for the candle filter).

In terms of the sustainability of both filters, each is formed of a ceramic mixture and then fired in a kiln. The process is relatively environmentally friendly, though each organization (PFP and iCATIS) recommends using higher efficiency kilns rather than just any kiln. While we are unable to assess first-hand the overall life cycle of either filter, ceramic filter producers generally recommend replacing the filter every 1 to 3 years. Further, the process of firing the ceramic for each filter is relatively simple as long as a proper kiln is accessible. The process may be taught to and then lead by community members; both PFP and iCATIS claim that this is an important part of their practice.

Technical and Implementation Standards

Included with their water filtration system, Potters for Peace provides a manual for proper filter use. The illustrated page of instructions regarding initial use as well as maintenance issues was helpful in getting started and would certainly come in handy if troubleshooting were to occur. iCATIS, on the other hand, did not provide a manual for use (though we did obtain their candle filter directly from Dylan Terrell of CATIS-Mexico's advisory board so they may provide manuals to their intended users in developing regions). In any case, a usage manual seems to be a relevant inclusion when delivering systems to the end user, as they will in most cases be used privately in the household. Both filters come equipped with a catchment tank, though that of the clay pot filter (the 5 L bucket) is somewhat small and therefore not capable of holding a significant amount of water. Of course a taller bucket might be used (and is in some cases), but the 5 L bucket, considering how deep down the clay pot sits inside it, requires regular emptying in order to prevent standing water accumulating in the clay filter element. As for the ceramic filter, it may be inserted in any appropriately sized water-jug neck, though it does need to be sealed in place.

As for the development of technical standards, increasing the flow rate of each filter seems to be the one thing worth looking into. While both filters are expected to pass 1 to 2 L of filtered water per hour, this will only provide sufficient daily water for an entire household if the filter is frequently being filled throughout the day. Considering that this may not be doable in every case, it is relevant to look into ways of increasing flow rate for each filter. For the clay pot filter, if the surface area of the filter's bottom were increased, this would allow for a greater flow rate. Likewise, increasing the filter's volume would produce greater pressure from the head of water in the filter, forcing more water through per hour. In the case of the candle filter, the flow rate we observed was below expectations, even after a few weeks of running water through. As the filter tank is capable of holding up to 19 L of water, a greater initial load would have forced more water through the filter per hour. Other than that, the candle filter seems to be less open to modification, as part of its appeal is its small size. However, one thing that could possibly be augmented is the size of the combustible material added to the clay mixture. Larger combustible particles would leave larger pores during firing, though holes too large might hurt the filter's effectiveness in eliminating bacteria.

Overall, the technical and implementation standards of both PFP and iCATIS have been developed over years and are relatively sound. Slight alterations to the design of each filter might need consideration, although it is likely that many of these options have been considered by the respective organizations.

Lessons Learned

Our biggest challenges stemmed mainly from time constraints. Having to obtain the candle filter from Dylan (iCATIS) all the way from Mexico took some time. By the time both filters had arrived and were installed in the lab, we only had a few weeks before end of the semester. An important aspect of testing water filters is assessing their life-cycle and necessary maintenance timelines. With only about a month to test the filters, we were unable to evaluate the integrity of either filter over time. It was evident that the flow rate of each filter improved over time, though with only about a month of testing, it is hard to know whether or not the rates would continue to improve (especially for the candle filter). Looking forward, we would like to keep the filters in possession of Columbia's Civil Engineering department so that they may be used for further, more complete testing by students participating in the Engineering for Developing Communities course. In this way, the time-consuming process of obtaining the filters may be avoided.

Some other hurdles we faced that were more easily overcome included the following: The ceramic candle filter's base broke in shipping but a makeshift replacement was fashioned out of a water jug equal in diameter to the one holding the filter element; our inexperience in bacteria testing was mitigated through the assistance of John Feighery (Ph.D. ‘13); and a comprehensive list of the realized advantages and disadvantages of each filter was comprised, the details of which are mentioned above.

Further, in considering the lessons learned through completing this project, it seems relevant to think about how user friendly these filters really are. On one hand, the filters are relatively easy to use and maintain (when compared with an alternative, the bio-slow sand filter), but they are also somewhat delicate. The cost of a clay pot filter replacement ($4 to $6) seems to be in a price-range that would cause the user to take care in operating and maintaining the filter, though purchasing a new one if necessary would hopefully not break the bank. With the filter life expectancy of 1 to 3 years, their delicacy seems a permissible shortcoming considering how much money they will save in providing clean water to those in developing regions in need.

Finally, our project is meant to be only the first step in hopefully a continuous process of learning more about the behavior and best use of ceramic water filters. As a large portion of our team’s time was limited simply by the work of coordinating the ordering the delivery of both the clay pot filter and the candle filter, it is our hope that future teams, both in the Engineering for Developing Communities class and others, will take advantage of the presence of the filters on campus and their potential for further research on water supply for communities in need. There are many ideas which our group would have liked to have learned more about and poses as research ideas for future students. One idea concerns the filters’ removal efficiencies for contaminants other than those measured in this study, such as viruses and pathogens; whether the filters are effective at removal of different contaminants indicates whether the filters may be applicable in one community versus another. Future teams should also consider having more varied, controlled influents or influents from different sources to simulate contaminants of different concentrations (for example, varying levels of *E. coli* and turbidity) to attempt to determine whether the filter is always effective at removal, or whether a high enough concentration of a certain contaminant yields only a certain percentage reduction. Additionally, if future teams continue to work on John Feighery's mWater application, there is certainly the potential to integrate the two projects; one idea would be to automate the measurement of *E. coli* contamination by use of the app and establish how effective this technique would work in the field. Most importantly, future groups should consider the effectiveness of the filters over an extended period of usage and time; while our team had only about two weeks to conduct testing, it would be interesting to see how prolonged use (or negligence) of the filters affected their performance of removal and flow rates.

WORKS CITED

[1] http://water.org/water-crisis/water-facts/water/

[2] http://www.biosandfilter.org/biosandfilter/index.php/item/299

[3] http://www.pilgrimafrica.org/about/about-pilgrim-africa/

[4] United Nations. *Millennium Development Goals Report for Uganda 2010*. 2010.

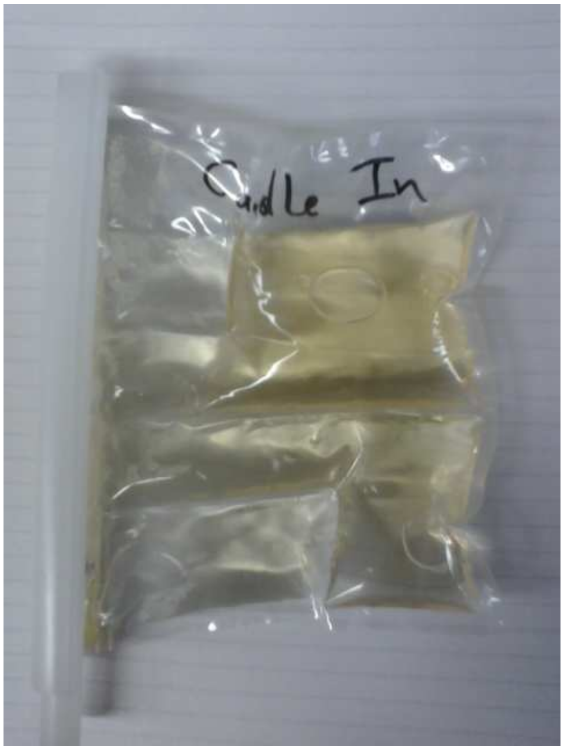
[5] See e-mail conversation between Stephen Forbes, Mark Reiner, Dylan Terrell, and Otis Poisson in the Appendix.

[6] http://pfp.he207.vps.webenabled.net/?page_id=63

[7] World Health Organization. WHO (2006) Guidelines for drinking-water quality: first addendum to third edition.

[8] vanHalem, D., van der Laan, H., Heijman, S.G.J., van Dijk, J.C. and Amy, G.L. *Assessing the sustainability of the silver-impregnated ceramic pot filter for low-cost household drinking water treatment*. Physics and Chemistry of the Earth 34(1-2): 36-42. 2009.

APPENDIX: PHOTO AND E-MAIL DOCUMENTATION

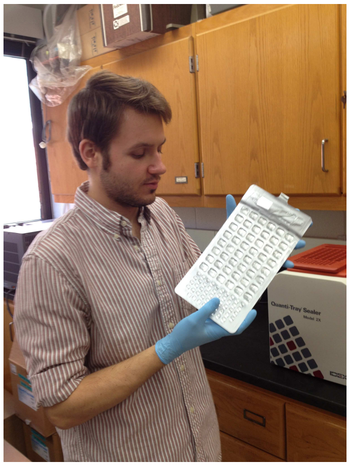


Compartment Bag Test (CBT): Candle In

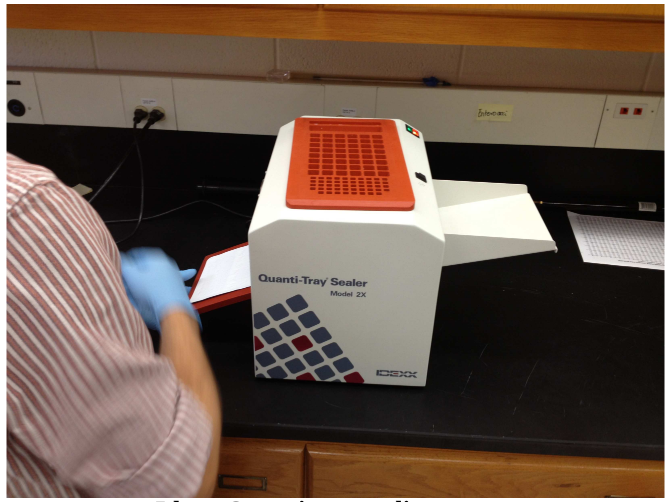
CBT: Candle Out

CBT: Pot In

CBT: Pot Out

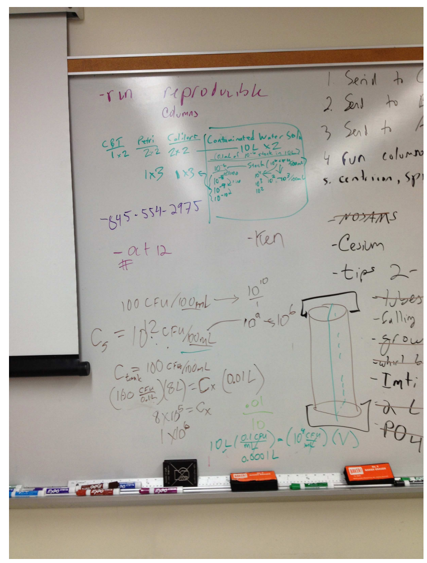


Evaluation of Idexx test

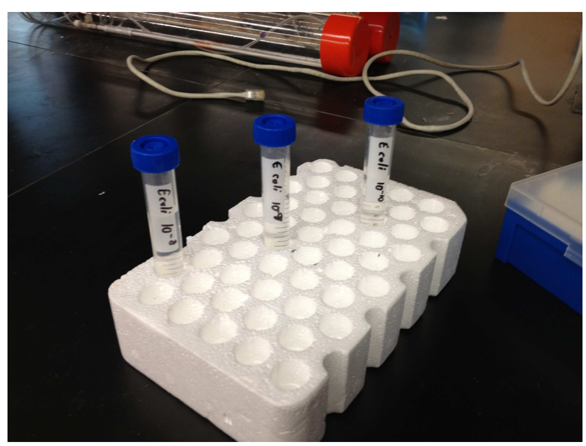


Idexx Quantitray sealing process

Entry of contaminated water into candle filter



***E. coli* stock dilution calculations**



***E. coli* stock serial dilution**

Project 2: Clay filters

Dylan Terrell <dylanterrell@gmail.com> Wed, Mar 6, 2013 at 5:29 PM
To: "sf2615@columbia.edu" <sf2615@columbia.edu>
Cc: "ajl2171@columbia.edu" <ajl2171@columbia.edu>, "ngo2102@columbia.edu" <ngo2102@columbia.edu>, "obp2104@columbia.edu" <obp2104@columbia.edu>, "dylan@icatis.org" <dylan@icatis.org>, "Reiner@icatis.org" <reiner@icatis.org>

Hello All,

I apologize for the delay in response. My computer charger broke earlier this week and finding a replacement in Mexico has proved much more difficult than intended, and hence why I am emailing from an iPod. Please feel free to send future emails to my dylan@catis-mexico.org email (not sure how to change that on here).

Anyway, we would be happy and excited to be a part of your research/study. I've copied Dr. Marcos Reiner to this email chain as well of iCATIS.

I feel that I should start off with a very brief history/explanation of all this "CATIS" stuff. iCATIS is the larger umbrella organization, located in Colorado, started by Dr. Reiner, myself, and various other engineers and professionals a number of years ago. CATIS-Mexico is the first "CATIS" center located outside of Atotonilco, Mexico (in the state of Guanajuato). I won't go into all of the gory details, but the long-story short is that the iCATIS ceramic water filters are iCATIS technology currently being produced on site at the CATIS-Mexico Institute. Dr. Reiner is PhD engineer and on the Board of Directors for iCATIS, and I currently serve as the on-ground Executive Director for CATIS-Mexico (separate but very intertwined organizations). So, I figured it would be good to get us both in the loop as Marcos and I have worked together on these filters for a long time and he can help with the more technical questions where I can help with logistical and on-ground studies we've done.

I have received just a very brief introduction to the work you are/will be doing. Could someone take the reigns and fill us in on the work you will be doing, general timeframe, and what you could use from us?

To give some quick background on our filters: they are ceramic "candle" models, which make for a smaller and more robust package than traditional pot filters. We guarantee 1-2L an hour average filtration rate making one filter system sufficient to provide drinking water for a family of six. Our conservative analysis shows that this can reduce the costs of the current alternative (buying 20L bottles of water) by 100 times. We have also had various analysis done on our filters, both in-house and by independent labs. All of our tests have shown turbidity removal to below 2 NTU when spiked with 350-600 NTU. And total coliform removal has consistently come back to the "no detect" levels...however, I cannot tell you the exact log removal number as I don't have that information.

Our filters are part of a greater platform. They are burned in a sustainable burning, double-dome, "MK Kiln." It should be noted that both the MK Kiln and our ceramic filters were invented/designed by iCATIS' Director of Research and Development, Dr. Robert Marquez. The kilns can reduce standard emissions from brick kilns by at least 80%, while also reducing fuel usage and burn time by 50% respectively. Currently, we work in a large artisanal brickmaking area of Mexico (responsible for roughly 10% of Mexico's brickmaking prpduction). The industry is highly competitive and profits are razor thin. Consequently, people burn what is both available and cheap (trash, tires, bottles, etc) in open-air kilns. The MK Kiln is attractive to the state as it reduces emissions, and it is attractive to brick makers as it reduces costs in the long haul. As we move forward and start building on the platform of the MK Kiln, we can start adding value added products, like our ceramic water filters, which provide a much needed service to the area while also increasing profits for brickmakers in the long haul.

All of the work we do is partnership with local community organization, namely CEDESA, who has 50+ years experience in working with local rural communities in the area. The long-term goal is to continue to spin-off these technologies into micro-enterprises for the communities we serve (i.e., filter molding business, system construction business, filter replacement program business, etc).

I won't go too much further for now, but I thought some background would be good. We would be happy to send you a couple of filter systems, and I will investigate the costs of that and get back to you soon.

I would also be happy to send any literature and information we currently have on our filters...just as soon as I get access to my computer again.

I hope this helps get you all started. Fill us in on the scope of the project when you get a chance. And please feel free to send any questions you have along the way.

I look forward to hearing more, and thank you all for your consideration. I hope all is well.

Suerte,
Dylan

Enviado desde mi iPod
[Quoted text hidden]

Project 2: Clay filters

sf2615@columbia.edu <sf2615@columbia.edu> Fri, Mar 8, 2013 at 5:15 PM
To: ajl2171@columbia.edu, ngo2102@columbia.edu, obp2104@columbia.edu
Cc: dylan@icatis.org, Marcos Reiner <reiner@icatis.org>

Had very informative discussion with Mark who provided some very good resources (attached), I will put in CourseWorks when I get a chance, but didn't want you to have to wait. He put to rest the notion that the standard clay pots take a year after completed before they can be used to treat water (they don't), but he identify other issues about them, such as breakage and kiln fuel. Don't know if time will allow but may want to consider a LCA (life cycle analysis). {Remember my comments are not suggestions or recommendations, just something to consider, and to do with as you see fit...it will not affect your grade.)

You representation was well done and looking forward to the final product.

S. Forbes

Project 2: Clay filters

Otis Poisson <obp2104@columbia.edu> Sat, Mar 9, 2013 at 12:13 PM
To: dylan@catis-mexico

Cc: "sf2615@columbia.edu" <sf2615@columbia.edu>, "ajl2171@columbia.edu" <ajl2171@columbia.edu>, "ngo2102@columbia.edu" <ngo2102@columbia.edu>, "obp2104@columbia.edu" <obp2104@columbia.edu>, "dylan@icatis.org" <dylan@icatis.org>, "Reiner@icatis.org" <reiner@icatis.org>

Hi Dylan,

Thank you for getting in touch with us and for providing a bit of background as to what you guys are doing at CATIS-Mexico (from an iPod no less! Impressive). Here's a bit about our project:

The three of us (Alex, Nicole and myself) are working with a client in Uganda to develop an ideal water filtration implementation plan there. We are planning to assess and compare the functioning efficiency (flow rate, contaminant removal effectiveness, ease of use/maintenance, lifecycle etc.) of three different water filtration systems – the bio-slow sand filter, the traditional Potters for Peace clay pot filter, and a modified version of the ceramic filter such as your "candle" model. As this project is a component of a current class, by the end of the semester we will hopefully have reached some conclusions (though if need be, some work may be handed off to a subsequent class, such as lifecycle analysis). So really we now have exactly 2 months to acquire filters, test them, and devise a plan that seems to best fit our working partners in Uganda.

All that said, it would be very helpful (and greatly appreciated) if you were able to send us one of the "candle" filter system. Any additional literature and filter information, as you mentioned, would be beneficial to our efforts as well. Do you still think it would be possible to send along an entire system?

And a few more questions (I hope you don't mind): What is the anticipated curing time for your "candle" filters (something we would have to consider in planning out the next 2 months)? Is it possible to send already-cured systems or only a freshly fired one? And how did you initially acquire traditional clay pot filters? Did you fire them yourselves or did you get them from an outside organization such as Potters for Peace? We are hoping to get our hands on one that has already been cured – would you recommend just getting in touch with Potters for Peace?

I think that is all for now. Looking forward to hearing from you and keeping in touch throughout this process.

All the best,

Otis
[Quoted text hidden]

Project 2: Clay filters

Dylan Terrell <dylanterrell@gmail.com> Fri, Mar 15, 2013 at 2:03 PM
To: Otis Poisson <obp2104@columbia.edu>
Cc: "dylan@catis-mexico.org" <dylan@catis-mexico.org>, "sf2615@columbia.edu" <sf2615@columbia.edu>, "ajl2171@columbia.edu" <ajl2171@columbia.edu>, "ngo2102@columbia.edu" <ngo2102@columbia.edu>, "obp2104@columbia.edu" <obp2104@columbia.edu>, "dylan@icatis.org" <dylan@icatis.org>, "Reiner@icatis.org" <reiner@icatis.org>

Hi Otis and all,

Again, I apolologize for the delay in response. It has been very busy, and I have been largely in communities without access to internet.

To answer quickly, yes we can send you a system or two. I can get that moving first thing monday. The quickest way will be DHL or Fedex, but that will bring the cost up some. Another option is I could send some home with someone who will be traveling to the states on March 24th, if that's not too late? Let me know.

If we send Fedex, I'm guessing the total cost will be somewhere between $90 and $150 ($35-50 for filter systems/materials, and the rest in shipping). I can confirm exact cost for you on Monday.

As for your other questions, PLEASE read my first email. I believe I answered many of your follow-up questions already. We do not get our filters from Potters for Peace. It is a completely different design. We do all of our own clay and mix testing on our production site. We also fire our own filters in our own ecological kiln. Again, please read that first email as I believe it will answer most of your questions. I am happy to answer any follow-up questions after. .

As far as your "curing" question, I believe Marcos and Steve cleared that up. There is NO CURING TIME for our filters. In fact, I've studied this extensively, and I have never heard of a curing time for any ceramic filters; so, I'm really not sure where that information is coming from? In any case, I can say for certain that our filters do not require curing. They will arrive at your doorstep ready to test.

The other email I sent also begins to address some of the broader social and ecological implications of our filters, which I hope would be a part of any sustainability study.

Let me know any other questions you may have, and I will get back to you on Monday with shipping information.

Thank you much,
Dylan

Enviado desde mi iPod
[Quoted text hidden]