A Study of the Feasibility of Creating a Ceramic Water Filter Factory in Limpopo Province, South Africa

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Abstract

In the summer of 2010, a Jefferson Public Citizens team traveled to Thohoyandou in the Limpopo Province of South Africa to conduct a feasibility study for building a ceramic water filter factory there. The region suffers from high incidences of HIV and of diarrhea resulting from waterborne illnesses. Membrane filtration and turbidity tests of water samples from over 200 households in two rural communities reveal that only 3.9% meet World Health Organization standards. An in-home survey about current water practices and water beliefs was administered in these homes. Participants ranked the desired traits of a water treatment technology and results suggest that ceramic water filters would be a socially acceptable solution for members of the two rural villages. These filters are a simple, effective, easy to use, and easy to maintain technology that can be locally manufactured with available resources. The team investigated willingness-to-pay for water treatment and for the filters. Over 96% of participants would be interested in buying a filter. The availability of raw materials was determined and clay sample analysis has begun. The team interviewed possible potters with whom to partner and chose the most suitable candidate. Initial contacts were also made at the municipal Department of Health and government health clinics to explore opportunities for filter subsidies, filter promotion, and water-health education programs. Based on the positive results of the project, several members of the group plan to continue their work and return to the region to facilitate the creation of a ceramic water filter factory.

Introduction

Approximately 1.1 billion people do not have access to an improved water supply (Watkins). The World Health Organization defines an improved water supply as a household connection or access to a public standpipe, a protected well or spring, or a source of rainwater collection that provides at least 20 liters per person per day and is available within one kilometer of the person's home (WHO/Unicef, 2000). Unimproved water supplies often contain waterborne pathogens which can lead to gastrointestinal infections, dehydration, stunted growth, cognitive impairment, and death. The United Nations estimates that, at any given time, patients suffering from waterborne diseases occupy about 50 percent of all hospital beds in the world (United Nations, 2006). Unsafe drinking water results in the deaths of about 1.9 million people annually (Watkins). Because diarrhea inhibits nutrient absorption, waterborne diseases can also lead to malnutrition, which causes impaired cognitive development, stunted growth and leaves children more susceptible to malaria and other enteric diseases (Petri et al., 2008).

Inappropriate, unsustainable technologies and systematic corruption in both donor agencies and recipients have done little to address these costs of unclean water. Decades of large-scale development projects have failed to deliver on promises of adequate sanitation and water services for 42 percent of the world's population (WHO/Unicef, 2005). Progress on improving water sources is misleading as water may be re-contaminated during collection, transport, or storage, particularly in communities without thorough hygiene education. As climate change drives decreasing river water levels in some areas, turbid water and contamination during extended storage time becomes more frequent. Making any advancement in the delivery of potable water and improving health outcomes for underserved populations depends on the introduction of sustainable, scalable solutions. These technical solutions must prevent contamination not only at the source but also inside the household before consumption for a large, economically-challenged customer base. The team's ultimate goal was to provide consistent access to potable water at the
household level in a way that is financially and environmentally sustainable and scalable to other communities, and to provide income opportunities for target populations.

Limpopo Province, South Africa, the location of this study, has the fourth largest population in South Africa with 4 million people, but it has the third lowest number of households with access to piped water. Only 32 percent of children in Limpopo Province have access to an improved water source. Through a longstanding partnership with communities near the city of Thohoyandou and with the University of Venda (UNIVEN), the team compiled preliminary research data that justify an exciting opportunity to develop an environmentally and financially sustainable, scalable ceramic filter factory business. The low-tech, low-cost, colloidal silver-enhanced ceramic water filter (CWF) can provide a point-of-use solution to the health burdens caused by unclean water.

A recent review of the literature sponsored by the World Health Organization concludes that simple, socially acceptable and low-cost interventions at the household (point-of-use) and community level have the potential to significantly improve the microbial quality of household water and reduce the risk of diarrheal disease and death, particularly among children (Clasen, Nadaseni, & Menon, 2006). In a recent meta-analysis of water-quality interventions aimed at reducing diarrheal disease, Clasen et al. (2006) report that household water interventions are more effective in improving water quality than interventions at the source and that household water treatment can be more cost-effective in the long run compared to centralized water treatment.

One of the most promising point-of-use water treatment technologies is the ceramic water filter, manufactured with local labor using clay, water, and a combustible organic material (such as sawdust or flour). When the clay filter is fired in a kiln, the sawdust (or other combustible) is burned out, leaving tiny pores through which the dirty water flows. This filtration process physically removes suspended sediment and larger microorganisms. Zero-valent silver nanoparticles (10-100 nm diameter) are also embedded in the porous ceramic filter, and have been shown to improve treatment performance by disinfection (Oyanedel-Craver & Smith, 2008). The pot-shaped filter is placed in a larger, plastic container with a spigot to also provide a safe-storage reservoir. Two recent studies have reported that these filters can effectively remove *E. coli* bacteria and turbidity from water (Kallman, Oyanedel-Craver, & Smith, 2010; Oyanedel-Craver & Smith, 2008). Pathogenic strains of *E. coli* can infect human gastrointestinal systems and result in diarrhea and dehydration. The removal of *E. coli* is a good indicator that the filter is effectively purifying the water, since *E. coli* is similar in size to other waterborne bacterial pathogens; if the filter can remove *E. coli*, then it is likely removing other bacteria and larger protozoan pathogens. It is important to also remove turbidity because some pathogens tend to adsorb to particles.

Filter factories are gradually spreading throughout the developing world thanks to the efforts of several non-governmental agencies like Potters for Peace and FilterPure. In a recent study of global filter factories, Rayner (2009) reports there are 35 established filter factories in 18 countries and filter production at these factories exceeds 40,000 filters per month. There are currently a few factories established in Africa, including factories in Rwanda, Kenya and Ghana. However, there are no CWF factories in South Africa or surrounding countries.

The team sought to determine the feasibility of starting a CWF factory to serve Limpopo Province, where reliable access to purified water remains limited. The proposed factory, as envisioned by the team, will be added to an existing pottery business. It will use local labor and primarily local resources. This factory will be built on a bottom-up approach, informed by input from community members collected through an in-home survey and interviews with community leaders, clinic managers and officials in the municipal Department of Health. The team investigated the feasibility of the factory from four different angles: human health benefits, technological performance, demand-side economics and supply-side economics. They also evaluated social acceptance and perceptions, critical components of any community engagement project.

**Methods**
The team approached the search for a scalable, point-of-use household water treatment system from an interdisciplinary perspective. The team developed and conducted a survey about water perceptions and willingness-to-pay for two rural villages in Limpopo Province. Household water quality was evaluated in over 200 homes. Regional non-governmental agencies and government health clinics were identified as potential customers for the filter factory. Finally, local potters were interviewed as possible candidates to host the filter factory.

A 50-question survey was developed by the team in conjunction with faculty advisors from the University of Virginia and the University of Venda. The survey contained questions that, after analysis, would help the team determine if moving forward with the construction of a factory was warranted. In order for any business to be successful, there must be a need demonstrated by the consumers for the product being sold. There are many point-of-use water treatment options, ranging in sophistication, expense and ease of use, so it was necessary to determine if CWFs are the best possible solution for the consumers in Limpopo Province. The product that will be marketed must be a proven solution to the problem and socially acceptable to the communities of the region. Keeping all of these factors in mind, the team developed a survey that focused on water beliefs, water storage and treatment practices, desirable traits in a water purification technology and perceptions of proposed clay water filtration technology. Questions also included general demographics and income questions to help determine consumers’ ability to pay. The survey was given to participants in two rural villages, Tshapasha and Tshibvumo, which take part in a long-standing relationship between the University of Virginia (primarily through the Center for Global Health) and UNIVEN called the Water and Health in Limpopo Project. Surveys were conducted when an adult member of the home was available. In-country student partners, who are nursing students at the University of Venda, facilitated communication. GPS coordinates were taken from every home, to make sure all areas of the villages were represented. The UNIVEN partners complete community outreach in the villages as part of their nursing curriculum, and were therefore familiar with the geographical area and the community members. They made sure that areas farther from water sources were included in the survey so as to get a complete sample of village residents’ opinions.

A drinking water sample was collected from every home surveyed in Tshapasha and Tshibvumo. The survey administrator asked the survey participant to bring a sample of water from the supply that is used for drinking. Most often the sample came from a storage container inside the home or from a pipe in the yard. The participant was asked to collect the sample in whatever vessel he or she would normally use. Stored water can be further contaminated by using an unclean vessel or if unwashed hands or containers are used to retrieve the water. By asking the household member to access the water in the usual manner, the team could measure the amount of contamination that is entering the body due to unhygienic water practices. The water sample was kept in a cooler for the duration of the time spent in the village and during transport to the Microbiology Laboratory at UNIVEN.

The samples were subjected to a membrane filtration test in which five mL of the household sample were diluted to 100 mL and passed through a sterile 45-μm membrane filter (Millipore). The membrane was placed in a Petri dish prepared with m-Coliblue24 broth or Eosin Methylene Blue (EMB) agar and incubated at 35 °C for 24 hours. After incubation, the number of Escherichia coli (E. coli) and total coliform colonies were counted and the results were reported as the number of colony-forming units per 100 mL. Some samples contained too many colonies to count, and were further diluted with deionized water and retested. The turbidity of the sample was also recorded using a turbidimeter.

Through talks with one of our community partners, Professor Maluleke of the Nursing Department, and information from other community members, the team came to recognize the importance of the health clinics in the community and the role they play in health education. The team became interested in investigating possible collaboration with and distributions through the public clinics. Professor Maluleke suggested seven local government clinics as a representative sample of public clinics in the region. Informal interviews were conducted with the clinic directors to gauge their willingness to become an integral part of the education and marketing that is necessary for the successful distribution of the CWFs. The interviews included questions about: the average number of patients seen a month, how many and which villages the clinics served, number of doctors and their frequency at the clinic, number of nurses, percentage of male and female patients, education levels among patients of different ages, common ailments and incidences of diarrhea. The team asked about the clinics’ education programs and whether they included information on water purification and safe practices. The team also inquired about the
home-based care workers who made house calls in the villages. Some clinics could provide more specific information about the water sources and water purification methods used in the communities they served. The investigators explained the CWF project and attempted to gauge the effectiveness of the clinic as a marketing and education source for the factory. Initial contacts were also made at the municipal Department of Health. These meetings, although brief, were promising that a future partnership involving subsidies, education, distribution and/ or marketing could move forward.

For the supply-side component of the feasibility study, the team investigated sources of materials for the factory and also reviewed possible partner potters. The materials investigated include: plastic buckets, clay, sawdust or other combustible material, spigots and colloidal silver. Inquiries were made at building supply stores in the city of Thohoyandou and along the main business corridor outside of the city. Sawdust can be cheaply obtained at local hardware stores. Clay is locally harvested by potters. Local potters were identified by a community contact and visits were made. Criteria for selecting a potter included: ease of distribution from the potter’s existing facility, size and sophistication of the potter’s facility, amount of pottery skill and experience, connection to and support from the community, number of employees, interest in community health, business skills and potential for expansion.

Clay samples were collected from each potter’s source, which often included both wet and dry clay which were mixed together for use in pottery. The clay samples were brought back to the Civil and Environmental Engineering Laboratory at the University of Virginia for analysis. The analysis seeks to find the optimal mixture of the sample clay with sawdust and water to produce the CWFs. The analysis involves fabricating ceramic test disks from the clay and testing them for hydraulic conductivity using a constant head permeameter test and for microbial transport.

Results

A portion of the in-home survey was used to determine the relative importance of various characteristics of a water treatment technology within the community. These characteristics included: water quantity, ease of use, cost, local availability, taste, coloration and odor of treated water and supply chain. The community determined that local availability was most important and quantity filtered was least important. Several different treatment options, including CWFs, free chlorine treatment, coagulant/flocculant treatment, solar disinfection and biosand filtration were scored on the aforementioned characteristics using the rankings listed in Sobsey (2008). Based on the importance rankings from the market survey, the CWF was selected as the most appropriate point-of-use technology, with biosand filters as a close second.

When asked if they would be interested in buying a ceramic water filter, 96.3% (184/191) of the participants who answered, responded ‘yes’. Ninety five and six tenths percent of participants said that if filters were to become available they would buy one either immediately or within the next six months. The most common reason participants answered “within the next six months” was to allow for the expense to be added to the household budget. Willingness-to-pay answers revealed that the average participant would be willing to pay around $13 for a ceramic water filter. This result is inconsistent with the average amount households are willing to pay on a monthly basis for water purification technology, which is a little under $10. These payment responses, coupled with the need to budget, lead the team to believe that an expensive purchase during one month is less attainable for a household than smaller monthly purchases. This may be due to a lack of understanding the life of the filter or the life of comparative products available to the households.

Results show that 99% of participants store at least a portion of their drinking water until needed. Though 77% keep these storage containers covered, 72.6% obtain the water from a storage container in a way that could lead to contamination of the stored water, such as dipping a cup or other container into the stored water. Even small amounts of bacteria in the stored water may multiply over a short storage period. The majority of survey participants, 99.4%, know that diarrheal incidence will decrease if they get clean water and store it in a clean container in a way that does not lead to contamination.

Results demonstrated only 8 of 205 (3.9 %) water samples collected from households met WHO standards. The WHO’s standards for safe drinking water are < 1 colony forming unit (CFU) of coliform bacteria per 100 mL of water. The average of the water samples tested as a part of the survey was over 1800 CFU/100 mL. The standard for E. Coli is also < 1 CFU/100 mL. While 66.5% of households meet this standard, the combination of these numbers clearly shows a need for water quality intervention.
After meeting several local potters, the team made a preliminary selection of Noria Mabasa, an entrepreneurial potter who has been recognized by the South African government for her innovative work in the region. The team decided that it was best to partner with a potter who is already successful and who has sufficient access to resources in order to ensure the success of the factory and the greatest benefit to the community. Mrs. Mabasa will hire workers and sustain the factory for many years after construction is complete, providing filters for thousands of families. Mrs. Mabasa has access to a clay deposit, which she uses for her pottery business. Clay analysis is ongoing to determine the water to clay to sawdust ratio needed to make CWFs with the appropriate flow rate.

Discussion

Filter factories are gradually spreading throughout the developing world, with 35 established filter factories in 18 countries. Despite these successes, many filter factories fail to remain profitable and sustainable. Several factors likely contribute to failure, including lack of local interest in water purification technologies; lack of local NGO support; lack of a local entrepreneur with resources and skills to start a factory with appropriate understanding of how to operate a local business; and lack of natural resources (e.g. local clay deposit suitable for manufacturing ceramic filters). The limitations outlined above were addressed by this project, and the results give us the confidence to move forward with the construction of the ceramic water filter factory. Although there are significant limitations to the success of a ceramic water filter factory, we believe we have appropriately assessed the potential for success. Our assessment shows that the factory is necessary for the health of the community and likely to be successful. Based on home survey responses ranking the desired characteristics of a water purification technology, the CWF is the most appropriate technology for the region. The community has demonstrated an awareness of the connection between clean water and health, but lacks the resources and infrastructure to achieve those things. The ceramic water filter is a simple, effective, easy to use and easy to maintain water treatment technology that lasts for about two years. CWFs can be manufactured and sold locally in Limpopo Province by a manufacturer with community connections. The business can be promoted through water health education programs run by government clinics and non-profits.

A ceramic water filter factory can initially employ two full-time laborers. These employees can manufacture approximately 1000 filters per month that can sell at a rate between $10 and $25 per filter, including the plastic safe-storage container with a spigot. As explained above, surveyed households have an average willingness-to-buy of around $13, which is in this range. Possible partnerships with the Department of Health and in-country NGOs may result in subsidies that will allow distribution to families in the lowest income bracket. Monthly payment plans may also be considered. Filter sales will result in a monthly gross income between $10,000 and $25,000 per month. Filter raw materials only require transportation costs for the clay and sawdust, and a cost of less than $0.50 per filter for silver treatment. Other projected operating costs include advertising and fuel for the kiln. Capital costs include expenses for a kiln, filter press, hammer mill, thermistors (for better temperature regulation of a kiln), inventory storage and sieves. The current estimate on the total for these capital costs is $30,000. Production costs of each filter are estimated to total about $8. A cash flow model with estimates of input costs reveals that in order to recoup initial investment within the first year, filters would have to be sold at a price greater than $10.50. If filters were sold at $13 per unit, the average willingness-to-pay, the factory would have a net income (after subtraction of initial capital costs) of about $25,000 in the first fiscal year. With the life of a filter being 2-3 years, there will be a continued supply of customers every year based on when they make their first filter purchase. Ideally, we envision the Limpopo factory to be a pilot, with the potential of developing dozens of additional factories in South Africa throughout the rural countryside.

Now that the high potential for success of a CWF factory has been established, the next step towards bringing a clean water solution to the Limpopo Province will be to construct the factory. Equipment including a hammer mill, sieves, filter press and drying racks must be purchased. A kiln must be purchased or constructed on site. Marketing must include reaching out to local NGOs, the municipal government, health clinics and schools. Collaboration with government and community health programs on promoting a water and health curriculum will be essential to ensuring that the community recognizes the benefits that purified water will bring. Pamphlets and presentations must be put together outlining the importance of safe water practices and the role of CWFs. Further clay analysis must be done at UNIVEN to finalize the optimal clay/combustible/water ratio for use in the filters.
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References


Biographies

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**Alukhethi Singo** is completing her final year at the University of Venda studying both Microbiology and Zoology and she plans to continue on to graduate school to study medicine.