Mechanistic laboratory and field evaluation of sustainable point-of-use water treatment technologies to remove turbidity and deactivate coliform bacteria

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ABSTRACT:
A recent field study has demonstrated silver-impregnated ceramic filters (manufactured according to the design criteria of the non-governmental organization Potters for Peace) can effectively remove E.coli and reduce turbidity in untreated tap water. Ceramic filters were locally produced in San Mateo de Ixtatan, Guatemala from clay and sawdust and then treated with colloidal silver (which acts as a disinfectant). Thirty filters were distributed and observed for one year. An additional 42 filters were observed for nine weeks. They were analyzed for E. coli, total coliform, turbidity, silver concentration, and social acceptance. Over the course of the study, the average percent reduction in total coliforms and E.coli was 86.86% and 91.75%, respectively. The average effluent turbidity was 0.18 NTUs and average concentration of colloidal silver was 0.02 mg/L. Ten percent of samples showed an increase in effluent bacteria concentration relative to influent concentration. An additional ten locally produced filters were tested daily under ideal user conditions for 26 days. Average reduction in total coliform and E.coli bacteria were 90.90% and 95.72%, with 1.5% of samples showing an increase in effluent bacteria concentration. Overall users were satisfied with the filters, citing them as easy to use and maintain while improving both health and water quality. The findings of this study suggest the successful uptake of ceramic filters as a point-of-use water treatment technology in San Mateo de Ixtatan

INTRODUCTION

An estimated 1.8 million deaths occur each year due to a lack of access to safe water, sanitation, and proper hygiene of which 99.8% occur in developing countries and 90% are children[1]. These unnecessary deaths can be reduced with proper infrastructure and educational programs on water handling and basic hygiene. In the past decade, the benefit of such initiatives in developing countries has been well documented. In a comprehensive study of the occurrence of diarrheal disease, point-of-use household water treatment technologies reduced incidences by an average of 25%[2].

Since 2005 Professor James A. Smith's research group in the School of Engineering and Applied Science at the University of Virginia has been investigating the Potters for Peace filter design in the laboratory. Both the small pore size and disinfecting properties of colloidal silver have led to promising lab results with deactivation of bacteria ranging from 97.8% and 100%[3]. The research that took place during the 2008 summer extended prior work to investigate the field performance and social acceptance of ceramic filters in a controlled field study in San Mateo Ixtatan, Guatemala. The non-profit Ixtatán Foundation, which helped to establish a ceramic filter factory in the community, facilitated communication between study participants and the four University students carrying out the assessment.

Erin Kallman, an environmental engineering graduate student, led three undergraduate researchers chosen from a pool of University-wide applicants. Daniel Restivo, a civil engineering student, was chosen

for his work with the colloidal-silver-impregnated ceramic filters as part of his undergraduate senior thesis. Katherine Kline and Rachel Massey's combined backgrounds in Sociology, Anthropology, and Spanish rounded out the team.

There was no collaboration with a traditional host laboratory; most of the scientific equipment was brought from United States. Supplies to analyze drinking water included a turbidimeter, membrane filtration apparatuses and relevant materials to perform 2000 bacteria analyses, and 300 silver analyses. The field evaluation occurred from the end of May through August.

RESEARCH ACTIVITIES AND ACCOMPLISHMENTS OF THE INTERNATIONAL COOPERATION

Located in the highlands of Guatemala, San Mateo Ixtatan is a peri-urban community home to approximately 35,000 people[4]. It is the poorest community in the most impoverished department/state (Huehuetenago) of the country. An extensive water distribution system provides water from six distribution tanks to individual homes. A field study performed by Dr. Vinka Oyanedel-Craver in 2006 shows significant water quality deterioration as water flows from the distribution tanks to the individual homes. The decline in water quality suggests infiltration into the piped system.

In 2006, a San Mateo Ixtatan brick maker was given the proper equipment to produce ceramic filters and instructed in their use by a representative from Potters for Peace. Over the course of a year, 72 of the locally produced filters were distributed to individual households. Users were given basic instructions in their upkeep and use. The first 30 were distributed in August 2007. Influent and effluent water samples were tested for turbidity and bacterial removal using membrane filtration. Tests were performed after initial distribution and at 4, 10, 11, and 12 months. The remaining 42 filters were distributed in mid-June 2008. Filters were tested for bacterial removal for the first 9 weeks of use.

The 72 evaluated filters showed an average total coliform reduction of 86.86% and *E.coli* reduction of 91.75%. Though less effective than the filters tested in a laboratory setting, in general the locally produced colloidal-silver impregnated ceramic filters effectively reduce bacteria concentrations and improve water quality. From a technological point of view, the *Potters for Peace* filter design is a reliable point-of-use water treatment technology.

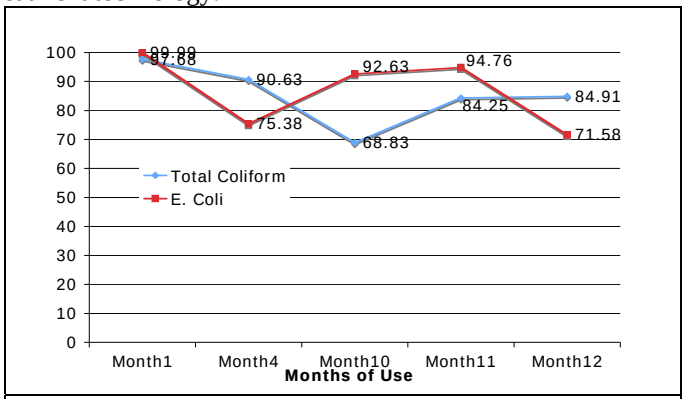

Figure 1: Reduction in bacteria for 30 filters over 12 months of observation.

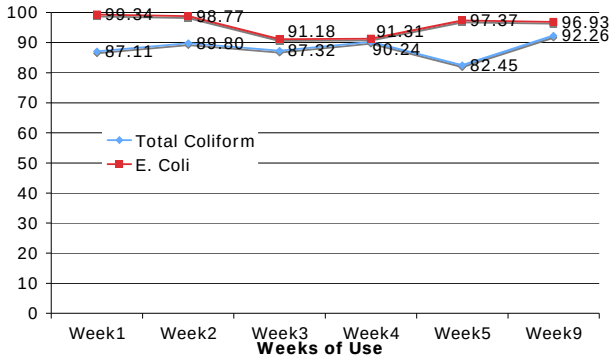

Figure 2: Reduction in bacteria for 42 filters over 9 weeks of observation.

However, influent concentrations of bacteria were greater than effluent concentrations during 10% of sampling. One or more of the following factors likely causes this:

1) The influent and effluent samples may have different initial concentrations of bacteria
2) Potential flaws and/or variability in the manufacturing process
3) Recontamination of the filtered water due to improper handling

To evaluate the extent to which manufacturing variability and user habits impact filter performance, 10 locally produced filters where evaluated by researchers under ideal conditions. Compared to filters used in the field, the "lab" filters showed a greater average reduction by 4% in both total coliform and *E.coli* bacteria, suggesting variability in the manufacturing process does not have a significant impact on filter performance. Only 1.5% showed an increase in effluent bacteria, suggesting user habits have a large impact on filter performance.

Prior to distribution a 200ppm solution of colloidal silver is applied to the inside and outside of the ceramic filters. The WHO and USEPA have set the exposure limit for colloidal silver in drinking water at 0.10mg/L. For all testing the average silver concentration was 0.02mg/L (Table 1). Based on both field and lab results, colloidal silver is not leaching at a concentration that would negatively impact human health.

Table 1: Average and maximum concentrations of colloidal silvers

Filter use	Mean [Ag]	Maximum [Ag]
12 hours	*0.02 mg/L*	*0.09 mg/L*
24 hours	*0.02 mg/L*	*0.03 mg/L*
1, 2, 4 weeks	*0.02 mg/L*	*0.04 mg/L*
10 months	*0.02 mg/L*	*0.02 mg/L*

Interviews were also conducted with study participants in order to gain understanding about the community's perception of the quality of its drinking water, causes of diarrheal disease, and acceptance of the new filter technology. Users identified the ceramic filters as a practical and necessary step towards improving family health; only one of the study participants withdrew.

The Ixtatán Foundation collaborated with the University of Virginia by familiarizing the community with the project's goals, suggesting student translators, and identifying families that would participate in the study. Researchers developed and taught a six-class workshop on proper hygiene and safe water practices which has since been adopted by a local high school funded by the Ixtatán Foundation.

BROADER IMPACTS OF THE INTERNATIONAL COOPERATION

The interdisciplinary research team was comprised of three undergraduate students and one graduate student with different academic concentrations. Dan Restivo and Erin Kallman have backgrounds in while Rachel Massey and Katherine Kline have backgrounds in Anthropology, Sociology, and Spanish. The diverse experience of the team members ensured the project had the cultural, linguistic, historical, and technological knowledge necessary to carry out a successful field evaluation of the effectiveness of a silver-impregnated ceramic filters as a point-of-use water treatment technology in San Mateo Ixtatán.

To understand community perception of health issue, water treatment as a priority, and whether the silver-impregnated filters are a viable and sustainable technology, interviews were conducted with the female head of the households. While interviews were conducted, the engineers analyzed the water samples from the tap water and filtered water to measure the effectiveness of the filters in terms of reducing *E. coli* and coliform bacteria. The engineers also collaborated with the local filter factory workers to optimize the technological aspects of filter production.

The supplement award expanded the original scope of the current award. The summer study in San Mateo Ixtatán facilitated preparation for and execution of a larger assessment of ceramic filters. The time allotted for research in San Mateo Ixtatán has prepare E. Kallman for the more extensive investigation, and established a small-scale precedent. The challenges to precision and accuracy faced in performing a field evaluation in a location as remote as San Mateo Ixtatán served to strengthen the researchers' ability to improvise and innovate when scaling up to the larger assessment. Similarly, the challenge of working in a indigenous community, where language is often a barrier and illiteracy rates are high, required a heightened cultural awareness and sensitivity to be carried over into future research.

Work conducted in a rural international setting has given the researchers greater insight into the difficulties of performing research abroad. In a laboratory setting the ceramic filters are uniformly made, used, and handled, eliminating biases and validating results. In San Mateo Ixtatán such a high level of control over the experiment is impossible to obtain since the filters are locally produced and researchers must trust the users to properly use and maintain them. The results obtained in the field from bacteria tests and user interviews reflect of the technical performance of the filters and their social acceptance and usability. Advancing the use of the filters in San Mateo Ixtatán allowed the research team to be a contributing force behind the greater movement of implementing point-of-use water treatment solutions in rural communities.

Collaborations between the University of Virginia and the Ixtatán Foundation have created a strong bond between the two institutions. This relationship will continue to grow as future UVA students continue to work under the common goal of providing clean water and good health for the people of San Mateo Ixtatán.

DISCUSSION AND SUMMARY

As foreigners implementing a technology in a developing community, the project was faced with unique barriers. Despite language and cultural constraints, researchers were able to work closely with the local filter producers and users to improve the technological performance of the silver-impregnated ceramic filters. Significant reductions in bacterial contamination and positive reception from the community demonstrate the successful uptake of silver impregnated ceramic filters as a point-of-use water treatment technology in San Mateo, Guatemala. The IREE program should continue to fund similar implementation projects working in non-traditional international settings. For all involved it was a formative experience dealing with the interface between users and technologies.

ACKNOWLEDGEMENTS

Include any relevant information including:

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BRIEF BIOGRAPHIES OF RESEARCHERS

Erin Kallman received the B.S. degree in Chemistry from the University of Virginia in 2006. Following a year working as an environmental scientist, she returned to the University of Virginia to pursue a Ph.D. degree in Civil and Environmental Engineering with a concentration in environmental engineering. Since 2007, she has been studying point-of-use treatment technologies with a focus on the *Potters for Peace* ceramic filter design.

Katherine Kline is in her third year of studies at the University of Virginia, pursuing B.A. degrees in Anthropology and Spanish. She hopes to continue her studies after graduation with a possible concentration in public health policy.

Rachel Massey received B.A. degrees in Spanish and Sociology from the University of Virginia in 2008. Currently, she is working for a non-profit organization, Phoenix of New Orleans. She plans on returning to graduate school with a focus in Biology.

Daniel Restivo received the B.S. degrees in Civil and Environmental Engineering from the University of Virginia in 2008. His undergraduate thesis was titled *Comparing the effectiveness of silver application methods in ceramic filters*. He is continuing his studies in civil engineering with a concentration in hydrology, water resources, and environmental fluid mechanics at the University of Washington.