Investigation of the Potters for Peace Colloidal Silver-Impregnated Ceramic Filter: Intrinsic Effectiveness and Field Performance in Rural Nicaragua

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Abstract
Potters for Peace is a US-based NGO that manufactures colloidal silver-impregnated ceramic filters in developing countries, and partners with local NGOs who independently implement safe water programs. This study investigated the intrinsic effectiveness and field performance of the PFP filter by administering a survey to families using the filter, completing water quality analyses of pre- and post-filtration water in rural homes, and investigating the relationship between filtration rate, colloidal silver application, and bacterial inactivation. Results agree with historical data and show that the PFP filter is capable of removing 100 percent of bacterial indicators of disease-causing organisms. Although the ceramic filter alone removes a majority of the indicators, the colloidal silver is necessary to achieve 100-percent removal. However, research in homes indicates that an educational component including safe storage, cleaning procedures, and follow-up visits is necessary to ensure the intrinsic effectiveness of this filter is matched in the field. Further research on removal rates of protozoa, viruses, and contaminants, and the resistance of the colloidal silver layer to scrubbing, is needed. These results detail that, with an educational component, the PFP filter is an effective and appropriate technology that improves water quality and human health.

Keywords
Appropriate technology, ceramic filter, colloidal silver, developing countries, drinking water, point-of-use treatment.

INTRODUCTION

Potters for Peace (PFP), a United States-based NGO, introduces colloidal silver-impregnated ceramic filters in developing countries first by establishing micro-enterprises of artisans making the filters, and then by partnering with NGOs that distribute the filters to families. In Managua, Nicaragua, PFP works with a cooperative of potters, COFICE, to manufacture and market these filters for use in household point-of-use drinking-water treatment.

The ceramic filter itself is 30cm in diameter, 24cm high, and holds 7.1 liters of water (Figure 1). The filter sits inside the receptacle. Receptacles are either 20-liter plastic buckets or ceramic pots. A plastic spigot is inserted at the bottom of the receptacle. Lastly, a plastic or ceramic lid is placed on top of the filter and receptacle.

Figure 1. PFP Filter

Filters distributed in Nicaragua are produced at the COFICE factory in Managua. Pulverized clay (60 percent by weight) and screened sawdust (40 percent) are mixed and press-molded using a 10-ton hydraulic jack. The filters are then fired at 887ºC. After cooling, the filters are tested to ensure a filtration rate between 1 and 2 liters per hour. Two milliliters of 3.2-percent strength Microdyn colloidal silver is mixed with 250 mL of filtered water and applied with a paintbrush to those filters meeting the filtration rate standard. After drying, the filters are marked with a trademark and an individual serial number, and sold to NGOs. The NGOs then distribute the filters in independently implemented safe-water programs in rural communities.

Safe water is a critical need in rural Nicaragua. Of the rural population, only 59 percent has access to safe water and only 68 percent has access to safe sanitation (UNICEF, 2001). One reason for this lack of access is that in October 1998, Hurricane Mitch devastated Central America, causing over 7,000 deaths in the region and US$560 million in damage to water and wastewater systems in Nicaragua alone (USAID, 2001). In May 1999, the United States Congress authorized US$621 million in aid under the Emergency Supplemental Appropriations Act.

A portion of these funds was used by USAID to investigate point-of-use water treatment. To this end, USAID installed and monitored 40,000 sand filtration units in Nicaragua. Follow-up education was found to be critical to the correct and continued use of this system (Bosche, 2001). In addition, USAID contracted with Jubilee House Community, Center for Development in Central America (JHC-CDCA), to study the intrinsic effectiveness and field performance of the PFP filter. JHC-CDCA is an intentional Christian community living in Nicaragua and working closely with a community of hurricane-displaced persons. One of JHC-CDCAs projects is the distribution of the PFP filtration system to provide safe drinking water within this community.

JHC-CDCA contracted with Alethia Environmental to provide investigation of the intrinsic effectiveness and field performance of the PFP filter. Ms. Lantagne spent three weeks in Nicaragua in October 2001 conducting experiments on the filter and sampling water quality in rural homes using the filter. Further research was conducted in November-December 2001 with filters transported to the United States. Three types of research were conducted: (1) water quality analyses of pre- and post-filtration water in rural Nicaraguan homes to determine if the filters were correctly and effectively used in the field; (2) investigations into variables relating to filtration rate and colloidal silver application and their effect on bacterial inactivation; and (3) challenge testing of the filter to determine removal rates of pesticides, VOCs, protozoa, and viruses. Challenge testing was conducted on only one filter, and due to quality assurance issues results are not included herein.

METHODS

Field sampling in rural Nicaraguan homes

Working with three partner NGOs in geographically diverse regions of Nicaragua, a total of 33 homes in seven communities were visited unannounced. In each home in which the filter was being used at the time of the visit, a survey was administered and water quality testing was conducted.

Survey. The survey was administered by PFP staff member Ivania Jerez in Spanish to the available family member with the most knowledge of family water use practices and health. The goals of the survey were to determine factors that correlated with correct filter use and to gain an understanding of the water situation in each home. The survey consisted of questions in three sections: water supply, filter usage, and family health. The water supply section included questions related to the distance to, wait at, and reliability of water at the family's usual source, and whether the family ever purchased water. The filter usage section included questions related to the age of, usage patterns of, cleaning procedures for, and problems associated with the PFP filter in the home. The family health section included questions related to hand washing habits, latrine presence and use, and childhood diarrhea in the last month.

Water quality testing. To ensure data comparability, filters and receptacles were emptied upon arrival at a home, and then filters were filled with the source water normally used by the family. Water quality sampling was then conducted on pre-filtration water. Water quality sampling on post-filtration water was conducted upon return to the home 2-4 hours later. Parameters sampled included those that could influence filter effectiveness and those that affect human health. Dissolved oxygen, turbidity, temperature, salinity, conductivity, pH, TDS, filtration flow rate, total coliform, *E. coli,* and hydrogen sulfide (H_2S) producing bacteria were sampled at each home pre- and post-filtration. Silver concentration was also sampled at each home post-filtration only.

Dissolved oxygen was measured with a LaMotte Modified Winkler test kit, turbidity with a Hach Pocket Turbidimeter, temperature with an Envirosafe thermometer, and salinity with a Sper Scientific salt refractometer. Conductivity, pH, and TDS were sampled with a Hanna HI9812 multimeter. Filtration flow rate was calculated using the volume of water in the receptacle divided by the time of filtration. All meters were calibrated once per week, and duplicate sampling was conducted at 10 percent of the homes.

Total coliform and *E. coli* were analyzed using Hach presence/absence (P/A) with MUG broth. Plastic sampling bottles were boiled for 10 minutes and then stored in clean, resealable plastic bags. Water samples were collected using sterile Whirl-Pak bags with dechlorinating agent and stored on ice no more than six hours before processing. 100 mL of each sample were transferred into the bottles and P/A with MUG broth was added using aseptic techniques. Samples were incubated for 48 hours, and analyzed every 12 hours for the color change indicating presence of total coliform and for UV fluorescence indicating presence of *E. coli.* After sampling, bottles were emptied, rinsed with isopropyl alcohol, and boiled in preparation for reuse. H_2S-producing bacteria presence was analyzed using Hach PathoScreen broth and these same procedures.

Three types of duplicate bacterial sampling were conducted. The first was duplicate samples of the finished water. The second was to collect a sample of the filtered water that was present in the filter when we arrived at the home and compare that result to the result from filtered water after the filter was emptied and rerun. The third type of duplicates were analyzed at a Nicaraguan laboratory. Source and filtered water samples from seven homes were enumerated for total coliform, fecal coliform, *E. coli,* and fecal streptococcus. All duplicate sampling met quality assurance standards.

Silver samples were collected in sterile bottles, preserved with nitric acid, and kept cold until their delivery to Toxicon Laboratories in Massachusetts, USA. Samples were analyzed using USEPA Method 6010B. Lab and field duplicates were analyzed and met quality assurance standards.

Review of historical laboratory data. PFP has worked extensively with the Center for the Investigation of Water Resources at the Autonomous University of Nicaragua (CIRA-UNAN) to test PFP filters for removal of bacterial indicators. CIRA-UNANs standard laboratory practice is to clean receptacles with detergent and sterile distilled water to ensure that receptacles do not recontaminate filtered water. CIRA-UNAN completes analyses for total coliform, fecal coliform, fecal streptococcus, and *E. coli* following procedures in Standard Methods (1995).

Filtration rate and colloidal silver investigations

Filtration rate investigations. A key variable in the PFP filter is the rate of filtration of water. In order to gain a better understanding of flow through the filter, pore size and changes in filtration rate over time were studied. In addition, finished water colloidal silver concentration and bacterial inactivation from filters with different flow rates were investigated.

Pore size was determined by Industrial Analytical Services, Inc. (IAS) in Massachusetts using a scanning electron microscope (SEM) with x-ray elemental analysis capability. A piece of a new filter with colloidal silver applied was sent to IAS for analysis. Changes in filtration rate over time were investigated using historical data, data collected in the home visits, and by collecting a filter and scrubbing it to determine if filtration rate improved.

Finished water colloidal silver concentration and bacterial inactivation at different flow rates were investigated by obtaining three new filters without colloidal silver with factory filtration rates of 1.0, 1.5, and 2.1 liters per hour. Water quality parameters, using water from a contaminated well and including bacterial testing using P/A methods, were analyzed before the usual 2.0 mL of 3.2-percent colloidal silver was applied to each filter. After the silver was applied, each filter was run with the contaminated water three times, with silver samples collected each run to determine silver concentration during the first three uses of each filter. Lastly, these filters were brought to CIRA-UNAN to enumerate total coliform, fecal coliform, fecal streptococcus, and *E. coli* removal rates.

Colloidal silver investigations. Two variables relating to colloidal silver were investigated: (1) the relationship between silver application method and bacterial inactivation; and (2) the relationship between colloidal silver concentration and bacterial inactivation.

To investigate the relationship between application method and bacterial inactivation, three filters with 1.6 liters per hour filtration rates and without colloidal silver were obtained from the factory. Two milliliters of 3.2-percent colloidal silver mixed with 300 mL of bottled water were then applied using three different mechanisms: (1) half of the mix on the outer part of the filter, half on the inner part; (2) one-third of the mix on the outer part of the filter, two-thirds on the inner part (this is the current practice in the factory); and (3) all of the mix on the inner part of the filter. Three runs with contaminated water were then conducted, with silver samples collected at each run. The filters were then delivered to CIRA-UNAN for analysis to determine bacterial removal rates.

To investigate the relationship between colloidal silver concentration and bacterial inactivation, five filters with 1.5 liters per hour filtration rates and without colloidal silver were obtained from the factory. Different concentrations of colloidal silver were applied to the five filters: (1) no silver; (2) 2 mL of 94 ppm silver; (3) 1 mL of 3.2-percent (32,000 ppm) Microdyn silver; (4) 2 mL of 3.2-percent Microdyn silver (this is the current practice); and (5) 5 mL of 3.2-percent Microdyn silver. Three runs with contaminated water were then conducted, with silver samples collected at each run. The filters were then delivered to CIRA-UNAN for analysis to determine bacterial removal rates.

RESULTS AND DISCUSSION

Water quality analysis in rural Nicaraguan homes

Of the 33 homes in seven communities visited, 24 homes (73 percent) were using the filter at the time of the unannounced visit. By community, the usage rate ranged from 33-100 percent. Higher usage rates were directly related to follow-up visits by a staff member or community leader associated with the sponsoring NGO. Usage rates were significantly lower where no follow-up occurred. Six of the nine homes not using the filter were not using it because the filter and/or the receptacle were broken. Of the remaining families, one was using the filter for bean storage, one family's filter was dry but assembled, and the last family would not show us their filter.

Survey. The survey was administered to all 24 families using the filter. Women and children were the primary water collectors, except in the case of an indoor supply, where all family members collected water. Families collect water an average of 1.8 times per day, and no person walked more than five minutes for their water. Four of the 24 families sometimes wait at the source for groundwater to recharge their well, and two of the 24 families have had their source run dry and moved to an alternate source for a time. Three of the 24 families sometimes purchase water. Twenty of the 24 families use shallow groundwater as their water source, three families use a river, and one family collects rainwater.

PFP filters were installed in the seven communities between six and 18 months before the sampling. The average family size using the filter was 5.7, including 2.7 children. Of the 2.7 children, 0.8 were under the age of five. Families predominantly use the filtered water for drinking only (50 percent), but some also use the water for cooking and making juice. Sixteen of the 24 families drink unfiltered water when the filter is empty or when they are away from their home.

Filtration flow rates ranged from 0.13-3.5 liters per hour. Using the average family size seen in this study, 14 of the 24 filters sampled did not have a filtration rate sufficient to supply each family member with 2 liters of drinking water per day.

All families clean their filter at minimum monthly, however most families (71 percent) use only a brush and no disinfectant. In addition, 78 percent of families clean their filter and receptacle with source water, thus opening up a potential contamination route. Because there is no residual associated with colloidal silver, receptacle contamination could lead to regrowth of bacteria.

Lastly, no family mentioned scrubbing the filter hard enough to remove build-up of suspended solids. One family's filter was sampled at a flow rate of 0.4 liters per hour. After scrubbing with a toothbrush, the flow rate increased to 2.1 liters per hour. This result agrees with the recommendations of Katadyn, a manufacturer who produces colloidal silver-impregnated ceramic filters for use in camping and other applications (undated). They recommend a regular scrub of their filter to remove particles attached to the ceramic and rejuvenate the flow rate. Katadyn specifically mentions that although this scrub removes a microlayer of ceramic, the filter is thick and can withstand many such scrubbings. A consideration in the PFP filter is whether repeated scrubbings will remove the colloidal silver layer. Although it can be observed during application of the colloidal silver that the liquid appears to sorb deep into the ceramic, further research is recommended to ensure the continued effectiveness of the colloidal silver after repeated scrubbings.

All families said they washed their hands, five of 24 families did not have a latrine, and three of the 19 under-5 year old children (16 percent) had had diarrhea in the last month. Four of 62 children under the age of 16 (six percent) had had diarrhea. No home with negative results for *E. coli* or H_2S-producing bacteria in their filtered water had a child with diarrhea in the last month. All homes with a diarrhea incidence tested positive for *E. coli* and H_2S-producing bacteria in the filtered water.

Based on the above survey results, it is concluded that follow-up visits to families are critical to continued filter usage, that the most common problem seen was breakage of the filter, that flow rate in 14 of the 24 filters was not sufficient to provide drinking water to the family, and that proper cleaning of the filter is crucial to continued effectiveness. It was recommended to PFP to encourage NGO follow-up, and to develop an educational brochure and a cleaning kit to accompany the filters.

Water quality testing. Results of the analysis of pre- and post-filtration water quality samples collected in the homes showed some interesting trends. Dissolved oxygen increased on average 1.3 mg/L after filtration, most likely due to increased air contact as the water drips from the filter. Turbidity decreased on average 83 percent, with all but two of the finished water samples below the WHO guideline value (1993) of 5 NTUs. An increase of 0.8 pH units was seen on average post-filtration due to alkalinity dissolved from the clay-based ceramic. All salinity values were below detection limit. Pre-filtration conductivity ranged from 30-450 mS/cm, with higher values in homes with piped water supplies. No change was seen post-filtration. Temperature remained constant pre- and post-filtration, except when ceramic receptacles were used. Then, the evaporative cooling effects of the ceramic led to a reduction of 2-3°C, which was appreciated by the families.

No silver sample collected post-filtration from the 24 homes exceeded or even approached the WHO guideline value (1993) and USEPA drinking water standard (2001) of 0.1 mg/L. Only two of the 24 samples were above the laboratory detection limit of 5 µg/L, with values of 6 and 15 µg/L.

All pre-filtration samples were positive for both total coliform and H_2S-producing bacteria (Table 1). Fifteen of the 24 pre-filtration samples were positive for *E. coli.* One filter (4 percent) removed total coliform. Six filters (27 percent) removed H_2S-producing bacteria (of note is that two filters were not sampled post-filtration). Seven filters (53 percent of the samples that had *E. coli* in the pre-filtration water) removed *E. coli.*

Table 1. Bacterial Removal in 24 Rural Nicaraguan Homes

	Pre-filtration Bacteria		Post-filtration Bacteria		Percent Removal
	Present	Absent	Present	Absent	
Total Coliform	24	0	23	1	4
H_2S-producing	24	0	16	6	27
E. coli	15	9	8	16	53

Of note is that all filters that removed H_2S-producing bacteria had plastic receptacles. In addition, all families whose water tested negative for H_2S-producing bacteria had a latrine and their filters also removed *E. coli* (if it was present). Thus, removal of bacteria and bacterial indicators was correlated with plastic receptacles and latrine ownership. Lastly, no home with a filter that removed H_2S-producing bacteria or *E. coli* had a child with diarrhea in the last month.

Duplicate enumeration sampling at CIRA-UNAN agreed with the P/A sampling. Of particular note is the fact that CIRA-UNANs enumeration of bacterial indicators found the source water significantly less contaminated than the post-filtration water. Thus, contamination is occurring in the stored water in the household and/or due to recontamination in the receptacle after filtration.

Review of historical data. In the laboratory, when the receptacles are clean, it can be seen that the filters with colloidal silver remove the majority of the bacteria (Table 2). It is of note that even without the colloidal silver, the filter removes a significant percentage of the bacteria (Jun 2000).

Table 2. CIRA-UNAN Bacterial Removal Data (1999-2001)

Date	# of filters	Description	Percent Removal			
			Total Coliform	Fecal Coliform	Fecal Strep	*E. coli*
Jul 2001	2	2 years old – used in restaurant	100	100		
Jun 2000	3	new – with colloidal silver	100	100	100	100
Jun 2000	3	new – without colloidal silver	90-99.5	82-100	100	82-100
Jun 2000	1	3 months old	98.9	100	85	100
Dec 1999	1	7 years old	100	100		
Aug 1999	8	New	99.9-100	100	100	100
Aug 1999	8	New	98.5-100	99.9-100	99.5-100	99.9-100

Filtration rate and colloidal silver investigations

Filtration rate investigations. SEM analysis showed that the composition of the filter is not uniform. There are both cracks and spaces. The cracks measure up to 150 microns in length, and the spaces measure up to approximately 500 microns in length. The pore size in areas not within a crack or space ranges from 0.6 to 3 microns. This pore size explains why filters without colloidal silver remove a significant percentage of the bacteria, for *E. coli* is 1 micron in size.

During the studies conducted to develop the filter, it was shown that filtration rate decreases with time (ICAITI, 1984). Similarly, filtration rates seen in the field in October 2001 were significantly lower than factory rates. When scrubbed, however, filtration rate was rejuvenated and it was recommended that users scrub the filter in order to maintain the filtration rate.

Lastly, finished water colloidal silver concentration and bacterial testing at CIRA-UNAN were conducted on three filters of factory filtration rates 1.0, 1.5, and 2.1 liters per hour. Silver concentration testing was completed for the first three uses of each filter. No sample exceeded the WHO guideline value or USEPA standard (0.1 mg/L) for silver in drinking water (Table 3). The finished water from the first use of each filter did have a significantly higher silver concentration than the water from the second and third uses. PFP currently recommends disposal of the water from this first use. Based on this data, it is recommended that this procedure be continued.

Table 3. Silver Concentrations in Finished Water during Initial Uses of Three Filters

	Silver Concentration (µg/L)		
Filtration Rate	1.0 L/hour	1.5 L/hour	2.1 L/hour
First Use	44	69	29
Second Use	11	19	18
Third Use	12	21	15

All three of the filters removed 100 percent of total coliform, fecal coliform, and *E. coli*, and 94-100 percent of fecal streptococcus. Thus, filters that are released from the factory within the specified filtration rate and with the current amount of colloidal silver do not cause a human health risk due to silver in the finished water, and do remove a significant percentage of bacterial indicators.

Colloidal silver investigations. The first investigation studied the relationship between application method and bacterial inactivation. Both filters with silver applied on the inner and outer parts of the filter removed 100 percent of total coliform, fecal coliform, and fecal streptococcus. The filter with silver painted only on the inner part removed 87.5 percent of total coliform, 80 percent of fecal coliform, and 91 percent of fecal streptococcus. Thus, it was recommended that PFP continue their current application process of painting silver on both parts of the filter. Removal rates of *E. coli* were not available for the silver investigations because the contaminated water used had no *E. coli.*

The second silver investigation looked at the relationship between colloidal silver concentration and bacterial inactivation. Currently, PFP applies 2 mL of 3.2-percent silver solution diluted in 250 mL of filtered water. All three amounts of 3.2-percent silver tested (1, 2, and 5 mL) removed 100 percent of the three bacterial indicators (Table 4). The filter with no silver removed the majority of the indicators, but not 100 percent. This is consistent with historical sampling and indicates that filtration by the ceramic itself removes a significant percentage of indicators. The filter with the 94-ppm silver solution removed a lower percentage of indicators than the filter without any silver. This is attributed to variations in indicator removal rates of the ceramic filter alone. It was recommended that PFP continue to use 2 mL (this includes a safety factor) of the 3.2-percent colloidal silver.

Table 4. Bacterial Removal Rates at Varying Concentrations of Colloidal Silver

	Bacterial Removal Rates				
Silver Applied	No silver	2 mL 94 ppm	1 mL 3.2%	2 mL 3.2%	5 mL 3.2%
Total coliform	98	76	100	100	100
Fecal coliform	97	63	100	100	100
Fecal streptococcus	82	76	100	100	100

Silver concentration samples were taken during the first three uses of each filter in both of these investigations. No sample was above the WHO guideline value or USEPA drinking water standard. Results were similar to those seen in the filtration rate investigation, with the first-use silver concentration significantly higher than the succeeding uses, but not above the standards.

CONCLUSIONS

This study agrees with historical data that shows that the PFP colloidal silver-impregnated ceramic filter design produces a filter capable of removing 100 percent of bacteria and bacterial indicators of disease-causing organisms. Although the ceramic filter itself removes a majority of the indicators, the colloidal silver is necessary to achieve 100-percent removal. However, research in homes using this filter indicates that this effectiveness is not matched in the field. An educational component that includes safe storage, aseptic cleaning procedures, and follow-up visits to ensure continued usage and replacement of broken pieces is necessary to ensure that the intrinsic effectiveness of this filter is matched in the field. Further research on the removal rates of protozoa, viruses, and contaminants, as well as the resistance of the colloidal silver layer to scrubbing, is needed. Based on these results it is concluded that, with the modifications suggested above, the PFP filter is an effective and appropriate technology that improves both water quality and human health.

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