Performance Evaluation of Ceramic Filter Candles

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Abstract: The performance of two ceramic filter candles and one silver-impregnated ceramic filter candle with a layer of activated carbon, randomly selected from those available in the Indian commercial market, were evaluated employing the *Escherichia coli* and poliovirus challenge tests and a long-duration filtration test mimicking the home treatment of water. None of the candles appeared reliable as microbiological water purifiers. The study indicated that specifications/standards should require filter candles to retain suspended particles down to a size of 1 μm to ensure at least a bacteriologically safe filtrate. Additional disinfection or boiling must be practiced during suspected outbreaks of waterborne viral diseases.

INTRODUCTION

In recent years, the ceramic filter candle (Berkefeld filter) and its modification (silver-impregnated, with or without activated carbon) have become popular in the developing world for the home treatment of ground water (hand-pump or dug well) or municipal water supply that is often suspect of inadequate treatment and/or contamination during distribution. Advertising claims these candles produce clean, pure, and microbiologically safe drinking water that attract consumers. It is essential that such claims accurately reflect their performance potential (Tobin 1984). Greater efforts are needed to control their quality and assess their suitability for tropical settings (Chaudhuri and Sattar 1990).

The number of studies to evaluate the performance of ceramic filter candles has been scanty even though specifications/guide standards and protocols for testing microbiological water purifiers are available ("Specifications" 1975; "Guide" 1987). In an Indian study (based on challenge tests using clay-spiked and artificially contaminated ground water), Kulkarni et al. (1980) observed that ceramic filter candles were satisfactory in removing turbidity but produced filtrates of unacceptable bacteriological quality. In a Canadian study ("Assessing" 1980) silver-impregnated ceramic candle devices, designed for in-line (countertop or under-the-sink) use, reduced the indicator bacteria (total coliforms) in sewage-contaminated water to below detectable level and heterotrophic bacteria (standard plate count) to usually less than 500 colony-forming units per mL (cfu/mL).

The present study evaluated the performance of two ceramic filter candles (C-1 and C-2) and one silver-impregnated ceramic filter candle with a layer of activated carbon (C-Ag). The candles were randomly selected from those available in the Indian commercial market. Performance testing included: (1) An *Escherichia coli* challenge test; (2) a long-duration filtration test, mimicking home treatment; and (3) a poliovirus challenge test. These three tests were carried out in their respective filter units supplied by the candle manufacturers. A filter unit comprised a top chamber (to house the candle and serve as a raw water reservoir) placed above a bottom chamber fitted with a tap (to serve as storage for the filtrate). Using a bubble test ("Specifications" 1975), the "maximum pore diameter" of the candles was estimated as 18.8 μm (C-1), 39.2 μm (C-2), and 16.0 μm (C-Ag). The Indian Standard ("Specifications" 1975) limits the maximum pore diameter of ceramic filter candles to 30.0 μm.

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E. COLI CHALLENGE TEST

A pure culture of *E. coli* (NCIM 2570), obtained from the National Collection of Industrial Microorganisms, was cultivated in broth to achieve a vigorous (logarithmic) state of growth, washed off nutrients by centrifugation, and introduced into 9 L of sterile tap water (a ground-water supply without chlorination) to produce a challenge level of 292,000–1,800,000 cfu/mL. This water was then poured into the top chamber of a filter unit and allowed to pass through the candle into the bottom chamber. After about 1 hr of filter run, duplicate samples of the filtrate were collected from the candle outlet and examined for *E. coli*, using a pour plate method (35°C incubation for 48 hr on plate count agar). Any silver residual in the filtrate, from the silver-impregnated candle, was neutralized immediately upon collection by adding 1.0 mL of Chamber's solution (7.3% sodium thiosulfate plus 5% sodium thioglycolate) to 100.0 mL of sample (Tobin 1987). Candles C-1 and C-2 were subjected to two challenge tests, whereas one test was performed with candle C-Ag.

According to the test results (Table 1), none of the candles satisfied the reduction requirement of microbiological water purifiers, e.g., a bacteria-free filtrate ("Specifications" 1975) or a six-log reduction ("Guide" 1987) in the bacteria challenge tests.

LONG-DURATION FILTRATION TEST

Purification of ground water by the filter candles was examined in a long-duration filtration test using water from a dug well. Characteristics of the water were pH 7.2–7.5, alkalinity 380–430 mg $CaCO_3$/L, turbidity 2.0–2.2 nephelometric turbidity units (NTU), heterotrophic bacteria 255–1,450 cfu/mL, and no detectable fecal coliforms. Eight to nine liters of the water were poured into the top chamber of a filter unit, twice daily (morning and evening), and allowed to pass through the candle into the bottom chamber.

TABLE 1. *E. COLI* and Poliovirus Reduction in Challenge Test

	E. COLI			POLIOVIRUS		
	Number in Filtrate (cfu/mL)			Number in Filtrate (PFU/L)		
Candle (1)	Test 1 (2)	Test 2 (3)	Log Reduction (4)	Sample 1 (5)	Sample 2 (6)	Log Reduction (7)
C-1	2,210[a]	4,750[c]	2.12–2.43	72,500[d]	100,000[d]	1.91–1.77
C-2	10,060[a]	21,700[c]	1.46–1.77	450,000[d]	433,000[d]	1.12–1.14
C-Ag	1,600[b]	—	3.05	475,000[e]	150,000[e]	1.21–1.71

Note: Influent challenge: [a]292,000 cfu/mL, [b]1,800,000 cfu/mL, [c]1,290,000 cfu/mL, [d]5,925,000 PFU/L, and [e]7,750,000 PFU/L.

Samples of raw water and filtrate were collected in the morning and examined for turbidity and heterotrophic bacteria using a pour plate method (35°C incubation for 48 hr on plate count agar). Any silver residual in the filtrate, from the silver-impregnated candle, was neutralized immediately upon collection, as described earlier. Following every 14 filter runs (7 days), a candle was either scrubbed (2–3 min of cleaning under running water with a soft bristle brush to remove adhering deposits) or scrubbed and boiled for 15 min (to sterilize the candle).

The ground water was spiked with settled sewage (1.0 mL–10 L of ground water) and used in the last 14 filter runs (22–28 days) to examine the reduction of fecal coliforms, as well as turbidity and heterotrophic bacteria, by the candles. The spiked water showed 1,000–4,000 fecal coliforms/100 mL and 5,800–20,000 cfu/mL of heterotrophic bacteria. A membrane filter method (44.5°C incubation for 24 hr on *M–FC* medium) was used for fecal coliform enumeration.

Performances of the candles in removing turbidity and bacteria are shown in Figs. 1 and 2. Days of operation and corresponding filtrate volumes in liters are shown in the abscissa. All three candles produced filtrates of comparable quality, throughout. Silver impregnation or differences in their maximum pore diameter were not significantly reflected in their performance. About one-log reduction in turbidity, heterotrophic bacteria, and fecal coliforms was observed. None of the candles produced a bacteria-free filtrate; however, filtrate from the silver-impregnated candle showed the least fluctuation in heterotrophic bacterial density. Filtrate turbidity ranges were 0.19–0.23 NTU (*C*-1), 0.16–0.21 NTU (*C*-2), and 0.13–0.16 NTU (*C*-Ag). Density of heterotrophic bacteria in the filtrates varied in the range 60–280 cfu/mL (*C*-1), 80–180 cfu/mL (*C*-2), and 60–160 cfu/mL (*C*-Ag) in the initial filter runs, and 300–5,000 cfu/mL (*C*-1), 300–2,700 cfu/mL (*C*-2), and 1,000–2,000 cfu/mL (*C*-Ag) in the filter runs using sewage-spiked

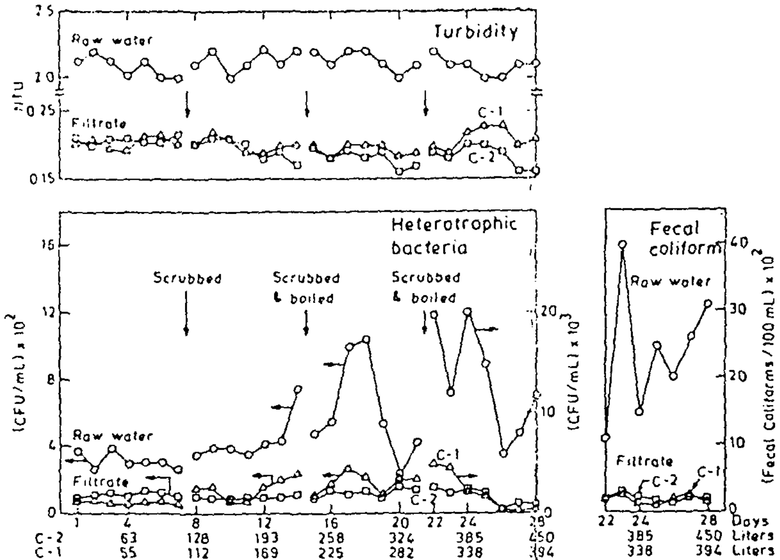

FIG. 1. Turbidity and Bacteria Removal by Ceramic Candles *C*-1 and *C*-2

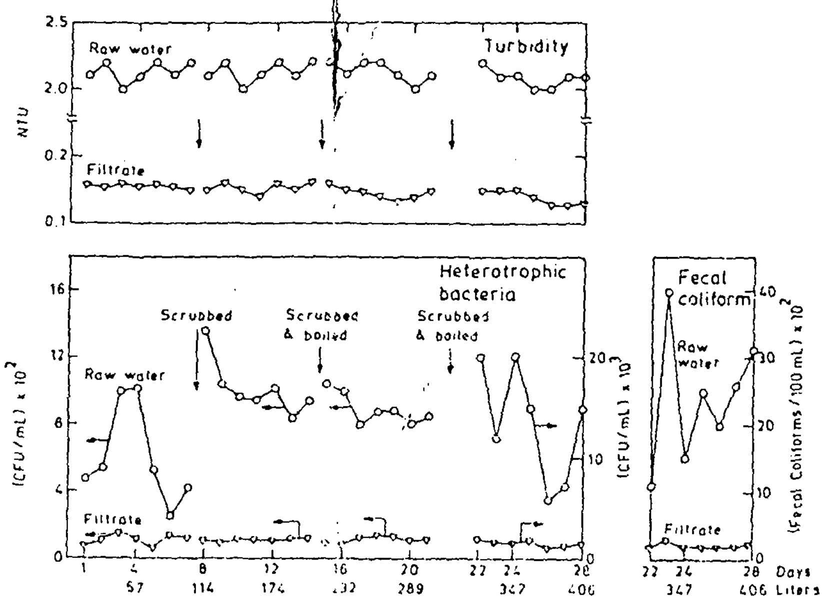

FIG. 2. Turbidity and Bacteria Removal by Silver-Impregnated Candle *C*-Ag

ground water. All three candles showed a range of 150–300 fecal coliforms/100 mL in the filtrate.

The superior performance of the Canadian candle devices reported ("Assessing" 1980) were primarily due to their finer pore diameter (suspended particles larger than 1.0 μm were retained on the candle surface) compared to the Indian candles tested. They were effective in removing bacteria by exclusion (Tobin 1987).

Over time, a considerable reduction in filtration rate was observed for all three candles. Filtration rate improved noticeably following either scrubbing or scrubbing and boiling. Actual measurements of filtration rate were not made, and the observation was based on the time taken for the water in the top chamber of the filter unit to pass through the candle into the bottom chamber. No significant change in performance was observed due to the effects of scrubbing, or scrubbing and boiling.

The bacterial colonies in the filtrate from the silver-impregnated candle (*C*-Ag) were different in appearance from those in the filtrates from the candles *C*-1 and *C*-2. Presumably, silver served as a selective agent, allowing only silver-tolerant bacterial strains to grow, as observed in the case of silver-impregnated activated carbon filters by Geldreich and Reasoner (1990). This may account for the lower degree of fluctuation in heterotrophic bacterial density in the filtrate from the silver-impregnated candle that was observed in the study.

The occurrence of pigmented bacteria (yellow, orange, pink, or brown) was observed both in raw water as well as in the filtrates from all three candles. These organisms generally appear to be part of the normal bacterial flora of clean water, often occurring in high numbers in waters low in nutrients (Geldreich and Reasoner 1990). The ratio of density of the pigmented colonies to total heterotrophic bacterial density was higher in the filtrates than in the raw waters for all three candles. This was contrary to what was reported for activated carbon filters by Geldreich and Reasoner (1990). They considered the pigmented bacteria as potentially useful markers that might aid in interpreting changes in the microbiological quality of the water treated by point-of-use water treatment devices. This aspect warrants a more systematic study.

POLIOVIRUS CHALLENGE TEST

Following completion of the long-duration filtration test, the candles were scrubbed and boiled, and subjected to a poliovirus challenge test using a procedure similar to the *E. coli* challenge test. Four liters of ground water (same as used in the long-duration filtration test) were spiked with poliovirus type 1, obtained from the Indian Council of Medical Research Enterovirus Research Center, to produce a challenge level of 5,925,000–7,750,000 plaque-forming units per liter (PFU/L). Two samples of the filtrate (0.5 and 2.5 L throughput) were collected from the candle outlet and examined for poliovirus, by plaque assay (*Smith and Gerba* 1982), on the MA-104 cell line obtained from the National Institute of Cholera and Enteric Diseases.

According to test results (Table 1), none of the candles satisfied the four-log virus reduction requirement for microbiological water purifiers ("Guide" 1987).

CONCLUDING REMARKS

The ceramic or silver-impregnated ceramic filter candles tested were not found to be *reliable* as microbiological water purifiers. They provided only a moderate barrier of safety for untreated ground water.

Ceramic filter candles bring about the physical removal of suspended particles like clays and microorganisms (free or bound to larger suspended particles) by depth filtration. British ceramic filter candles, with a maximum pore size in the range of 4.5–5.5 μm, were found to effect greater than four-log reduction of *E. coli* and other suspended particles down to a size of 1.0 μm (Frost, personal communication, 1992). In an Indian study (Joshi et al. 1984), laboratory-made ceramic filter candles with 90% of the pores in the size range of 1.2–5.0 μm produced filtrates with no detectable coliforms. Canadian ceramic candle devices that were able to retain suspended particles larger than 1.0 μm produced bacteriologically acceptable filtrates ("Assessing" 1980). A consideration of these findings and results of the present study indicates that specifications/standards should require ceramic filter candles to retain suspended particles down to a size of 1.0 μm (average size of bacteria) to at least ensure a bacteriologically safe filtrate. Such candles, however, may not retain human pathogenic viruses (because of their small size, 0.02–0.25 μm) unless they are bound to larger suspended particles. Additional disinfection or boiling must be practiced during suspected outbreaks of waterborne viral diseases.

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