Removal of microbes to World Health Organization requirements using a locally developed, low cost, micro-porous, ceramic water filter

J. J. Simonis, A. K. Basson and T. Selepe

ABSTRACT

The quality of drinking water can no longer be taken for granted and has been the subject of tremendous attention from pressure groups and the media due to poor service delivery in South Africa. Furthermore, many of the older water treatment plants are incapable of effectively reducing microbes to safe levels. Unfortunately there are various definitions of 'safe'. The South African government considers 10 or less viable *Cryptosporidium* oocysts an infective dose, while the USA and UK governments believe that one viable *Cryptosporidium* oocyst is an infective dose. To add to the confusion the World Health Organization recommends above 99.99% microbial reduction as safe. In Africa it really depends on how compromised your immune system is and age and nutritional level at the time of consumption of contaminated water. How can anyone protect themselves from consuming water contaminated with pathogenic microorganisms? The ceramic filter offers the poor a simple, effective and economical way of producing potable water. We report on the successful testing of a low-cost, locally produced ceramic filter (OUTBAC) with removal efficiencies in excess of 99.99% that therefore meets the World Health Organization household water treatment system criterion for safe water for a family of five at an affordable cost per year.

Key words | ceramic, filtration, low-cost, microbial, recommendation, WHO

J. J. Simonis (corresponding author)
Department of Hydrology,
University of Zululand,
Private Bag X1001,
Kwadlangezwa,
3886,
South Africa
E-mail: *simonisj@unizulu.ac.za*

A. K. Basson
T. Selepe
Department of Microbiology and Biochemistry,
University of Zululand,
Private Bag X1001,
Kwadlangezwa,
3886,
South Africa

INTRODUCTION

Various physical and chemical methods are available for domestic water treatment (WHO 2012). In Africa, however, ceramic filters used in households are seen as a superior, more cost-effective purification method when using raw water and poorly disinfected drinking water when compared with conventional centralised treatment and water reticulation systems (Lantagne 2001; Clasen & Boisson 2006). The small pore size of ceramic filters normally makes them effective in removing bacteria and protozoa but not viruses, which are much smaller and pass through the filters. Furthermore, the WHO (2011) is applying increasing pressure on the manufacturers of ceramic filters to comply with their recommended level of microbial reduction of 99.99% based on representative monitoring data from local, regional or national surveys. Such data should highlight the temporal and spatial variability with respect to protozoa, bacteria and viruses distribution in countries where the filters are produced.

Ceramic technologies currently used are pot, disk, or candle-shaped porous ceramic filters driven by gravity. The pore sizes vary down to 0.2 μm, efficiently removing bacteria and protozoa. The removal of pathogenic viruses from polluted drinking water is technologically challenging. The small particle size of viruses (25–200 nm) makes it possible to remove them using expensive nano-filtration and reverse osmosis, which are not suitable or affordable on a domestic scale.

Bacteriophages usually do not travel independently in water, however, but 'hitch a ride' on larger host bacteria.

doi: 10.2166/washdev.2014.042

These larger hosts, to which the virus is attached, may then be removed together with the viruses, either by filtration or by their inactivation through incorporation of metallic ions into their enzyme system in a chemical reaction, or by a combination of the two methods.

A micro-porous ceramic water filter with micron-sized pores was developed using the traditional slip casting process. The filter has a bi-modal pore size distribution which restricts microbes from passing through the ceramic filter (Simonis & Basson 2011). The locally produced filter has the advantage of low cost due to the usage of locally available raw materials, labor and expertise and can be manufactured at a cost of US $15 per filter (Simonis & Basson 2012, 2013). The ceramic filter was found to be highly effective in physically removing the bacteria, protozoa and suspended solids from local water sources and laboratory infected water (Simonis *et al.* 2014). With further improvements, which included a coating with metallic oxides, the filter can now also absorb bacteriophages (viruses and therefore complaint to World Health Organization (WHO) recommendations for household water treatment systems (HWTS). This filter system could therefore be used successfully to purify water for drinking purposes, especially water obtained from the available sources in the rural areas.

METHODOLOGY

Impregnation of existing HWTS involved dissolving soluble metallic salts as stock solutions. The ceramic was impregnated with the stock solutions using a capillary suction technique. The filters were dried and fired (kiln) in either an oxidizing (metallic oxide) or a reducing environment (metallic coating).

The inhibition effect of various low concentrations (1 mg L^{-1}), metallic solutions on a number of bacterial morphologies (*Escherichia coli* (ATCC770034), *Enterococcus faecalis, Klebsiella pneumoniae* (ATCC31488), *Staphylococcus aureus* (ATCC25925) and *Salmonella typhimurium*) were determined (Harman *et al.* 2010; Kim & Van der Bruggen 2010).

A number of microorganisms (bacteria, protozoa and viruses) were selected and enumerated according to WHO recommendation for testing the HWTS (WHO 2011). The enumerated solutions were filtered using the HWTS and both the solution and the filtrate were tested. The list of selected waterborne microbes used included:

(a) Bacteria: *E. coli, E. faecalis, K. pneumoniae, S. typhimurium* and *Staph. aureus* were inoculated and incubated at 37 °C for 24 h into a nutrient broth (Merck Cat. No. 107882) before filtration. Colony-forming units (CFU) were counted for both the pre and post filtrate for determination of the log reduction value (LRV) using the pour plate method (Van Soestbergen & Lee 1969).

(b) Protozoa collected from standing water ponds was filtered through the existing coated HWT system. Both the pre-filtrate (control) and post- filtrate sample were centrifuged and microscopically observed for the presence of protozoa. The protozoa concentration was determined by counting 10 microscopic fields and the average quantity of protozoa per microscope field was calculated. The average protozoa per microscope field were multiplied by the microscope factor (MF). The MF was calculated as follows:

$$\mathrm{MF} = \mathrm{ab}.\left(\pi \mathrm{r}^2\right)^{-1}$$

where a is the surface area (mm^2) on the slide; b is the reciprocal of the volume used on the slide; πr^2 is the surface area of one microscope field (Fitts *et al.* 2004).

(c) Viruses: somatic phages were enumerated using the double-layer method to cultivate the phages using *E. coli* (ATCC70078) as the selected bacterial host. The enumeration procedure was repeated for pre and post filtrate samples (Cornax *et al.* 1990; Clokie & Kropinski 2009; Simonis *et al.* 2014).

RESULTS AND DISCUSSION

Table 1 shows the inhibition effect of various low concentrations (1 mg L^{-1}), metallic solutions on a number of bacterial morphologies. From the results in Table 1 the most effective metallic solutions were selected for impregnation of the ceramic filters for further testing against microbes.

Table 2 indicates the filtrate LRV obtained through filtration of selected bacteria using non-coated (standard filter), metal and metallic oxide impregnated ceramic filters.

Both the coated and uncoated filters showed LRV effectiveness in excess of 6 for the protozoa removal after filtration.

Table 1 | Inhibition effect of metals on selected bacteria with X indicating metal inhibition

	E. coli	***K. pneumoniae***	***E. faecalis***	***S. typhimurium***	***Staph. aureus***
Metal	**Indicator of presence of coliforms in polluted water. Gram-negative, rods**	**Gram-negative, rod shaped bacteria**	**Gram-positive, spherical coccus**	**Gram-negative, flagellated, rod shaped bacteria**	**Gram-negative, grape like, irregular clusters**
$AgNO_3$	X		X		
$CuCl_2$	X				
$CuSO_4$			X		X
$FeCl_2$		X	X	X	
$FeNO_3$	X	X		X	
$ZnCO_3$		X			
$ZnSO_3$		X		X	X

Table 3 indicates the filtrate values (bacteriophages mL^{-1}) obtained through filtration (control samples) using non-coated (standard filter), metal and metallic oxide impregnated ceramic filters.

Table 4 indicates the international testing standards (USA: USEPA (1987) and NSF (2003) and WHO (2011) for HWTS.

From previous work (Simonis & Basson 2011, 2012, 2013; Simonis *et al.* 2014), the microbial contaminant is separated in the filter in three ways:

1. The narrow bi-modal particle size distribution, mechanical screening on the surface and the resulting filter cake build-up restricts the particle from passing through the porous ceramic filter (sieving). The surface build-up of filter cake simplifies cleaning the filter.
2. Limited depth filtration also takes place where smaller particles become trapped inside the ceramic as a result of the bi-modal particles size distribution of the pores. These particles become permanently trapped and can only be removed through removal of the outer layer through scrubbing/sanding.
3. The metal and metallic oxide enhanced ceramic surface allows for adsorptive retention where the particle is fixed to ceramic surface due to interactions between the particle and the coating.

Table 2 | LRV of non-coated and metal impregnated ceramic on water contaminated with selected bacteria

Metals	***E. coli* (CFU/mL) ATCC770034**	***Staph. aureus* (CFU/mL) ATCC25925**	***K. pneumonia* (CFU/mL) ATCC31488**	***E. faecalis* (CFU/mL) ATCC29212**	***S. typhimurium* (CFU/mL) ATCC700030**	***Psuedomonas aeruginosa* (CFU/mL) ATCC10662**	**LRV AVE**
Control	**74,000**	**9,000,000**	**110,000**	**2,290,000**	**8900**	**5300**	
Non-coated (LRV)	5	5	4	6	4	4	4.6
Ag^+	5	7	5	6	4	4	5.1
AgO	5	7	4	6	4	4	5.1
Cu^{2+}	5	7	5	6	2	4	4.8
CuO	5	7	5	6	4	4	5.1
Fe^{2+}	5	7	5	6	4	4	5.1
FeO	5	7	5	6	4	4	5.1
Zn^{2+}	5	6	2	6	4	4	4.5
ZnO	5	7	5	6	4	4	5.1
Average							5.0

Table 3 | Impact of non-coated and metal impregnated ceramic filters on water contaminated with bacteriophages (average reduction for *E. coli* host)

Sample	Bacteriophages per mL	LRV	Virus reduction (%)
Control	620,000		
Non-coated	20,500	1.5	98
Ag^{+}	7500	1.9	99
AgO	1000	2.8	99.8
Cu^{2+}	130,000	0.7	79
CuO	40	4.2	99.9
Fe^{2+}	19,000	1.5	96.9
FeO	12,500	1.7	97.9
Zn^{2+}	17,500	1.5	98
ZnO	160,000	0.6	74

Table 4 | USEPA, NRF and WHO microbial criteria for HWTS compared with the test results for OUTBAC HWTS

	LRV: USEPA (1987) & NSF (2003)	LRV: WHO (2011)		LRV: UNIZULU filter	
Microbe	Commercial filters	Highly protective	Protective	Non-coated	Coated
Protozoa	3	4	2	>5	>5
Bacteria	6	4	2	>4	>4
Virus	4	5	3	1.5	>4

The results in Table 2 as well as the protozoa results indicated that the uncoated filter (control) removed bacteria through physical sieving and limited depth filtration within the WHO recommendations with a LRV of greater than 4. The results in Table 3 showed that for the much smaller viruses the impregnation of the ceramic surface with metal and metallic oxides was necessary for absorbing the viral particles. The uncoated filter (using sieving and depth filtration) was showed to be ineffective against the viral particles.

Table 4 shows that the tested filter complies adequately with USEPA, NRF and WHO microbial criteria for HWTS.

CONCLUSIONS

The developed low cost ceramic water filter can capture and inactivate microbial indicators (bacteria and protozoa) through physical screening in a wide range of waters. The results are compliant with the WHO specifications for protozoa and bacteria for HWTS. The WHO also recommends an LRV 4 value for viruses. For compliance to WHO recommendations we used metal and metal oxide-enhanced ceramic surfaces to capture and inactivate bacteriophages through ionic absorption. Copper oxide-enhanced ceramic surfaces eliminated viruses to WHO recommendations. The locally developed and enhanced ceramic filter complies with WHO specifications for HWTS. Can this locally developed ceramic filter provide clean water to rural poor Africa at a cost of only US$15 per year?

REFERENCES

Clasen, T. & Boisson, S. 2006 Household-based ceramic water filters for the treatment of drinking water in disaster response: and assessment of a pilot programme in the Dominican Republic. *Water Pract. Technol.* **1** (2).

Clokie, M. R. & Kropinski, A. M. 2009 *Bacteriophages: Methods and Protocols, Vol.* 1: Isolation, characterisation and interaction. *Series: Methods in Molecular Biology*, Vol. 501. Springer, New York.

Cornax, R., Morinigo, M. A., Paez, I. G., Munoz, M. A. & Borrego, J. J. 1990 Application of direct plaque assay for detection and enumeration of bacteriophages of bacteroides fragilis from contaminated-water samples. *Appl. Environ. Microbiol.* **56** (10), 3170–3173.

Fitts, J. E., Laird, D. & Marshall, R. T. 2004 *Direct Microscopic Methods for Bacteria or Somatic Cells*, Chapter 10. Standard Methods for the Examination of Dairy Products, American Public Health Association.

Harman, B. I., Koseoglu, H., Yigit, N. O., Beyhan, M. & Kitis, M. 2010 The use of iron oxide-coated ceramic membranes in removing natural organic matter and phenol from waters. *Desalination* **261**, 27–33.

Kim, J. & Van der Bruggen, B. 2010 The use of nanoparticles in polymeric and ceramic membrane structures: Review of manufacturing procedures and performance improvement for water treatment. *Environ. Pollut.* **158**, 2335–2349.

Lantagne, D. S. 2001 Investigation of Potters for Peace colloidal silver impregnated ceramic filter Report 1: Intrinsic effectiveness. USAID P.O. 524-0-00-01-00014-5362.

NSF (National Sanitation Foundation, now NSF-International) 2003 *Microbiological Water Purifiers*. NSF P231, Ann Arbor.

Simonis, J. J. & Basson, A. K. 2011 Evaluation of a low-cost ceramic micro-porous filter for elimination of common disease microorganisms. *Phys. Chem. Earth* **36**, 1129–1134.

Simonis, J. J. & Basson, A. K. 2012 Making a low-cost ceramic micro porous filter and filter system for elimination of common pathogenic bacteria. *Phys. Chem. Earth* **50–52**, 269–276.

Simonis, J. J. & Basson, A. K. 2013 Manufacture of a low-cost ceramic micro porous filter for the elimination of microorganisms causing common diseases. *J. Water Sanit. Hyg. Dev.* **3** (1), 42–50.

Simonis, J. J., Ndwandwe, O. M., Basson, A. K. & Selepe, T. 2014 Removal of selected microorganisms using silver-impregnated and coated, low-cost, micro-porous, ceramic water filters. *J. Water Sanit. Hyg. Dev.* **4** (1), 37–42.

USEPA (United States Environmental Protection Agency) 1987 *Guide Standard and Protocol for Testing Microbiological Water Purifiers*. USEPA, Office of Drinking Water, Washington, DC.

Van Soestbergen, A. & Lee, C. H. 1969 Pour plates or streak plates? *Appl. Env. Microbiol*. 1969, **18** (6), 1092.

WHO 2011 *Evaluating Household Water Treatment Options: Health-Based Targets and Microbiological Performance Specifications*, 1st edn. World Health Organisation, Geneva.

WHO 2012 *Managing Water in Home: Accelerated Health Gains from Improved Water Supply*. www.who.int/water_sanitation/dwq/wsh0207/en/index6.html. (accessed 5 January 2012).

First received 15 March 2014; accepted in revised form 27 June 2014. Available online 22 July 2014