Ceramic Silver impregnated Pot filters for low-cost point-of-use drinking water treatment

Doris van Halem
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PRACTICA FOUNDATION

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1. Project Background

This chapter gives an overview of the background of this research project. In the first paragraph the introduction of household water treatment is described. Paragraph 1.2 discusses the organisation of Potters for Peace and the final paragraph introduces the CSF project.

1.1 Household water treatment

WHO/UNICEF assessed in 2000 that 1.1 billion people do not have access to 'improved drinking-water sources'. Consumption of unsafe water continues to be one of the major causes of the 2.2 million diarrhoeal disease deaths occurring annually, mostly children in developing countries [Sobsey, 2002]. Interventions in hygiene, sanitation and water supply make proven contributors to controlling this disease burden. The ambitious target # 10 established in the 'Millennium Development Goal' (MDG # 7) is "Halving the proportion of people without sustainable assess to safe water and sanitation by 2015".

Providing more than half a billion people with safe drinking water is a major task, especially since most of them live in rural areas. Despite major efforts to deliver safe, piped, community water to the World's population, the reality is that water supplies delivering safe water will not be available to all people in the near term [Agarwal et al., 1981; Feachem et al., 1978; IDRC, 1980]. It is not an option to wait for the long-tem solution of microbiologically reliable drinking water through distribution systems. According to WHO a short-term solution to meet the basic need of safe drinking water can be found in Household Water Treatment and safe Storage (HWTS). Apart from the advantage of a relatively early implementation of HWTS, recontamination can be prevented by treating the water at home.

Recontamination occurs between point of delivery and consumption, both during transport and in the homes (lack of safe storage). Currently several point-of-use (POU) treatment systems (table 1) have been developed and are in use all over the world. However, with highly varying results.

An appropriate technology complies with WHO guidelines on the quality and quantity of water. It ensures the guarantees that water for personal or domestic use is safe and therefore free from micro organisms, chemical substances and hazards that constitute a threat to a person's health.

Table 1 POU treatment methods

POU treatment	Disadvantages
SODIS (solar disinfection)	Only effective for clear water and difficult to gain high discharges
Chlorination	Chlorine is an expensive import product, bad taste
Boiling	Time consuming and extra costs for fuel, fetching wood
Coagulation-flocculation	Time consuming and expensive import product
Sedimentation	Low level of removal
Slow Sand Filtration (SSF)	Turbid water will clog the filter, uncertainty regarding the availability of sand and some level of expertise needed
BioSand Filters (Intermittent SSF)	Quality of filter uncertain not yet well established
Ceramic filters	Quality of filter uncertain not yet well established

1.2 Potters for Peace

Potters for Peace (PFP) "seeks to build an independent, non-profit, international network of potters concerned with peace and justice issues. We will maintain this concern principally through interchanges involving potters of the (overdeveloped) North and (underdeveloped) South. PFP aims to provide socially responsible assistance to pottery groups and individuals in their search for stability and improvement of ceramic production, and in the preservation of their cultural inheritance [PFP, 2001]." In this context PFP started to introduce ceramic colloidal silver-impregnated pot filters (CSP filters) in developing countries (figure 1).

The PFP filter pots are manufactured in a small factory in Nicaragua and then assembled to a complete filter. So far complete filters (filter pot, plastic receptacle, spigot and lid) have been mainly sold to NGO's for approximately US$ 7.
After installing a production facility in Nicaragua, PFP (in cooperation with Practica Foundation) have begun to scale up CSP filters production in other countries. This is done by involving local entrepreneurs to start their own factories. In 2000 factories were established in Mexico, Bangladesh and Cambodia. Furthermore factories were established in Haiti, Guatemala, El Salvador, Nepal, Pakistan, Uzbekistan and Ghana in 2001 and 2002.

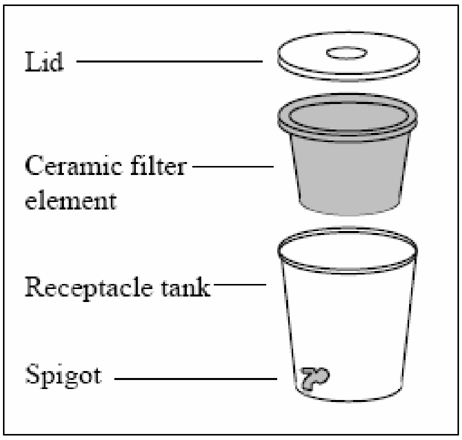

Figure 1 Ceramic Water Purifier, Cambodia [Roberts, 2003]

1.3 Ceramic silver impregnated filter (CSP) project

The initiator of the CSF project is the Practica Foundation. The Practica Foundation aims to facilitate research, development and commercial application of technology in the field of water and energy in developing countries. With the financial and technical support of Aqua for All the project has been made possible.
Aqua for All is founded by the Dutch water sector in 2002. The objective of A4A is sustainable development of drinking water supply, sanitation and water management in developing countries, funded with money and knowledge of the Dutch water sector. The CSP filters are imported to the Netherlands from 3 production locations; Cambodia, Ghana and Nicaragua. From the latter both filters with and without impregnated colloidal silver are imported. The project can be divided into 4 phases:

Phase 1 Provide credible performance data under laboratory conditions for ceramic silver impregnated filters to help speeding-up and scaling-up their implementation.

Phase 2 Evaluate and classify the performance of CSP filters in relevant rural locations by carefully examination and judging the efficacy of the CSP filter technology based on the testing data under conditions of observation and analysis (similar to phase 1).

Phase 3 Verify all test/quality assurance regarding the level of environmental risk reduction that occurs in the real world related to the level of performance and effectiveness of technologies purchased or used. This evaluation preferably results in a 'Declaration of Performance' regarding the removal efficiency of CSP filters.

Phase 4 In the final phase of this project the declaration is presented to WHO. Then CSP filters can hopefully be applied at many new locations in the world to contribute to reach the Millennium Development Goal # 7, target # 10.

Only the research that is carried out under phase 1 is subject of this report.

2. Problem Analysis

The problem analysis is split up into the removal efficiency of CSF, the role of silver and the physical filter characteristics. Paragraph 2.4 gives a description of the problem and in the final paragraph the objective is outlined.

2.1 Removal efficiency of CSP filters

The micro organisms that cause waterborne diseases are classified as bacteria, protozoa, viruses and helminthes [Levinson, 1996]. Table 2 shows that these four organisms belong to different kingdoms and are eukaryotic (containing DNA with a nuclear membrane), prokaryotic (without a defined membrane) and non-cellular.

Table 2 Biologic relationships of pathogenic microorganisms [Levinson, 1996]

Kingdom	Pathogenic microorganism	Type of cell
Animal	Helminthes	Eukaryotic
Protist	Protozoa	Eukaryotic
	Fungi	Eukaryotic
Prokaryote	Bacteria	Prokaryotic
	Viruses	Non-cellular

The level of removal depends on the size of the pores and the size of the organisms. The size of bacteria varies from 0.3 to 100 µm, depending on the shape. Protozoa feed on bacteria and other microorganisms, *Giardia Lamblia* and *Cryptosporidium* are common disease-causing protozoa. Protozoa range in size from 8 – 100 µm. Helminthes and fungi are large organisms and expected to be removed by ceramic filters. Viruses do not have the structure to reproduce themselves, which makes them the smallest of all disease-causing organisms, at 0.02 – 0.2 µm.

Potters For Peace aims to have a maximum pore size of 1µm (1 micron). This means that all particles larger than 1 micron should be trapped in the filter. Unfortunately, in reality the size of the pores are measured between 0.6 – 3 micron [Lantagne, 2001]. In the past various investigations have shown that CSP filters remove most parasites and bacteria, but there is only limited reliable scientific documentation available. It is known that the removal efficiency of CSP filters can differ greatly per filter, but it is unknown what these variations are. The performance of the CSP filters will be investigated in three contexts:

- Variations over time
- Variations at different production locations
- Variations in one batch of the same production location

CSP filters are tested in the factory by measuring the flow rate of the filter. Only when the flow rate is between 1 and 2 L/hr the filter is approved to leave the factory. This testing method gives some indication of the quality of the filter, but previous investigations [Lantagne, 2001] have shown that flow rates in the field are often outside the tested range.

2.1.1 Performance variations over time

A ceramic filter is used by a family over a period of a few years. During this period the pores gradually get blocked by the particles in the influent. The family can prevent the complete blocking of the filter by scrubbing the filter on the influent-side with a (tooth)brush. There is currently no scientific base for the performance variations of CSP filters over longer periods. What are the effects of the usage of the filter on the removal efficiency over a long period?

2.1.2 Performance variations at different production locations

Currently the CSP filter is manufactured according to the PFP design in various countries. It is uncertain if the removal efficiency of the filters produced at different locations is similar. The quality of the filters is possibly influenced by the manufacturing method and the materials. Although the method and materials are almost similar, slight differences in production are known. For example the clay is not of exactly the same composition. In Nicaragua filters are dipped in silver solution while in Cambodia the filters are brushed with the solution. It is unknown what the effects are of these differences in production.

2.1.3 Performance variations at one production location

A previous investigation [Lantagne, 2001] with 3 filters showed that the variations between filters from the same production location are large. Unfortunately this investigation is not done with more filters which would have made it more reliable. The reliability of CSP filters is an important issue and hopefully a research on the quality of the filters from one batch can give a solid scientific base to formulate the performances and the limitations of the product. It would also be interesting to investigate the performance variations between batches from the same manufacturer. This research should give an indication of the replicability of CSP filters.

2.2 Role of silver

The main removal mechanism of the CSP filter is that the larger particles are blocked by the smaller pores. But it is believed that a second inactivation mechanism for organisms contributing to waterborne diseases utilized in the PFP filter is colloidal silver. But there is insufficient knowledge regarding the exact mechanisms of colloidal silver in filters:

- What is the contact time needed for inactivation?
- What is the contact surface (depends on the manufacturing method)?
- What is the effect of chlorine on the silver (coating van silverchlorine)?
- What if silver is only applied on the effluent-side of the filter?
- Scrubbing does not seem to affect the efficiency of the filter, but what is the definite resistance of silver to the scrubbing?

There is currently little literature available on the inactivation mechanism of bacteria by colloidal silver. The only references found in literature are based on personal communication. Literature-based historic evidence on the inactivation of micro organisms by silver could contribute to the scientific proof of the role of the silver in CSP filters.

2.3 Physical filter characteristics

The uncertainties within this research do not only concern the silver and the removal efficiency of CSP filters. It is also not very clear what the pore distribution is in the filter and which parameters influence the flow rate.

2.3.1 Pore size and distribution

This testing method gives some indication of the quality of the filter, but it remains uncertain what the exact physical characteristics of the filter are. Several parameters should be considered to provide more insight in the characteristics of the filters:

- What is the pore size and length (influenced by material/mixing technique)?
- In the past the pore-size has been analysed at the tip of the filter only, which is expected to have larger pores than the bottom due to the manufacturing method. What is the distribution of the pores in the filter?

2.3.2 Variations in filtration rate

In the past it has shown that the filtration rate differs greatly between laboratory and the field. All filters that leave the factory have a filtration rate between 1 and 2 l/hour. In practice the filtration rate is often outside this range, often due to testing with varying water levels. But is it also possible that for example temperature has an influence on the flow rate?

2.4 Problem description

At this moment there are still many questions to be answered regarding the functioning of ceramic silver impregnated filters. The main questions are stated in this paragraph. These questions will hopefully lead to a more detailed problem description in the course of this project.

- Previous researches give an insufficient base of scientific evidence regarding the level of removal of the PFP ceramic filters.
- What are the variations in LRV of CSP filters during a long period of time?
- What are the variations in LRV at different production locations?
- What are the variations in LRV for the same batch from one production location?
- What is the replicability of CSP filters?
- There are insufficient references to literature to prove the role of silver in the removal of micro organisms.
- Does the colloidal silver have an effect on the LRV?
- Does the LRV change when the filter is scrubbed (especially in relation with/without silver)?
- Why is the flow rate different in the laboratory and in the field?
- What is the pore size distribution over the filter?
- What is the pore size/length of the ceramic filter and does it vary much between manufacturers and materials?

2.5 Objective

The questions in the problem description lead to an objective of this project. It is expected that the objective will be described in more detail in the future weeks of this project. The objectives of this research are:

- to gather scientific evidence of the removal efficiency of CSF over time, at different production locations and the same production location.
- to determine the replicability of CSP filters (use of statistics).
- to develop a test protocol for testing the filters in the factory.
- to conduct a literature study to investigate the role of silver in the removal of micro organisms.
- to investigate the role of the silver by researching filters with and without a colloidal silver layer.
- to provide more information on the material characteristics of the filter (pore size/length and distribution).
- to determine the differences in flow rate between laboratory and field conditions (eg. by fluctuating the temperature).
- to give a description of the operation and maintenance of the CSP filters.
- to develop an international performance research method for the CSP filters.

3. Project Approach

The research project is covers four main aspects; (1) monitoring the removal efficiency, (2) investigating the role of the silver, (3) investigating the physical filter characteristics and (4) the operation and maintenance of CSP filters.

3.1 Monitoring removal efficiency of CSP filters

The Log Reduction Value (LRV) is determined by measuring the parameters that are stated below. An indication of the experimental set-up is given in subparagraph 3.1.2.

3.1.1 Parameters

The LRV will be determined for *Escherichia* coli and total coliforms which are naturally present in Schie water (the Schie is a canalised river crossing the city of Delft). This should already give an indication of the LRV of bacteria, but not for viruses and protozoa. Therefore also MS2 phages and Sulphite Reducing Clostridia Spores (SRCS) should be spiked on the filters for a number of times.
The concentration of E-coli present in Schie water will probably not be very high. A higher concentration of the E-coli K12 is applied to increase the load on the filters. This will expectedly give an indication of effect of highly polluted water on the CSP filter.
The samples are tested on the microbiology, but both the influent and the effluent are also sampled and measured regarding pH, temperature, conductivity and turbidity. Each week the flow rate through the filter is measured.

Additional to the parameters listed above also the removal of some chemicals are investigated like silver, iron and alumina. Arsenic is not included because it is not expected that this will be present in the Schie water. Total particle counting should be considered too (to investigate the removal of particles) as well as dinoflagellate counting (to assess the growth of algae).

3.1.2 Experimental set-up

The efficiency of the filters is monitored by installing six filters from each of the three production locations for a period of about 12 weeks. The number of filters is based on the number available for this experiment. Therefore this number might increase if more imported filters prove suitable for the experiments. The six filters are selected after the determination of their clean water flux (a broad range of clean water fluxes would be optimal). The influent of these filters is water from the river Schie, a natural water body that flows through Delft. The laboratory of TU Delft has a pipeline from the river Schie, so this natural water body is most convenient to use. This influent is brought on the filters a few times per day (depending on the clean water flux) with a volume of approximately 7 liters per time. Weekly the influent and effluent of the filters are sampled and analysed for the parameters mentioned in the previous paragraph. For a minimum of 4 times some of the filters will also be loaded with a high concentration of E-coli, MS2 phages and SRCS. Spiking of MS2 phages will only be applied on the filters from Nicaragua (i.e. with and without silver), since it is a very costly procedure. It should be noted that the filters that are used for spiking E-coli and SRCS are probably no longer in the same state as the other filters. Therefore 4 filters per production location will not be used for this purpose.

To investigate the performance variations at one production location a second batch of at least 6 filters is imported from Nicaragua. For a period of approximately 6 weeks these filters will be loaded with Schie water. In case more filters are available then these filters can be loaded with a high concentration of E-coli and SRCS.

During both investigations the filters are maintained according to the manufacturer's instructions. After the first 12 weeks of the research the set-up will be maintained and after 2 more months the influent and effluent will be sampled one last time.

3.2 Role of silver

The role of silver in the filters is not fully understood. So first a short literature study is needed on the possible role of silver concerning the elimination of micro-organisms.
In the laboratory the role of silver can be investigated by using the two types of filters from Nicaragua i.e. the ones with and without colloidal silver. During the test described in paragraph 3.1 the filters from Nicaragua are spiked with MS2 phages approximately 4 times. This will give a distribution of the removal efficiency of viruses over time.
Additional investigations can be done by using different flow rates (contact times). It might also be interesting to investigate the micro-biologic degrade in a bucket with and without colloidal silver.

3.3 Physical filter characteristics

The research of the physical filter characteristics will be based on the pore size and distribution and on the flow rate variations.

3.3.1 Flow rate variations

Recent experiments have shown that the flow rates, obtained in the laboratory sometimes greatly differ from those obtained in the field. Possible factors that influence the flow rate are the temperature of the water and the water level in the filter element. The flow rate through the filters will also be determined at different water temperatures (eg. 15 – 35 degrees Celsius) and different water levels in the filter element.
What is exactly the influence of the flow rate on the removal efficiency? To investigate this, experiments with fluctuating flow rates are considered (eg. by bringing the filter under pressure).

3.3.2 Material characteristics

Currently the biggest disadvantage of the use of ceramic filters is the uncertainty of the quality of the filter. During the manufacturing of the filters there is no insight of what exactly is created in the filter. How consistent is the quality of one and the same manufacturer? And what influences the material characteristics of the filter, like pore size, length and variety? Is it clay and sawdust / ricehusk characteristics, is it the humidity prevailing at the mixing time, is it the mixing ratio, is it the pressing, the drying conditions, the firing curve, the cooling down speed that prevails as a determining factor? Or which other one? How long is the travel time of the water in the filter and are short-cuts created which get larger in time?
These uncertainties regarding the material characteristics are investigated in this part of the research. Pore sizes and distribution can be investigated by using the mercury porosity test and/or the bubble point test.

3.4 Operation and maintenance (O&M)

During the determination of the removal efficiency the filters will be operated and maintained according to the manufacturer’s manual. The manuals supplied by the manufacturer are specific for their equipment. For this study all significant features of the water treatment system are well described. The target user needs to be aware of the design, the installation procedures and the way of commissioning the system, including a full hygienic operation and daily maintenance. Monitoring the operation and maintenance for 12 weeks will give insight in the complexity and efficiency of the actions executed by the user. Additionally, a more intensive operation schedule will be followed by running the filters continuously and monitoring 24 hours a day for period of more than 6 days. Results of observations need to be included with time-dependent operations and maintenance characteristics.

3.5 Documentation

In this paragraph a short description is given of the documentation that is done next to the presentation of the results from the research described in the previous paragraphs.

3.5.1 Technology description

The technology description must contain both batch information and specific information per filter element. The size and condition of the filters must be described on the day of arrival, during and after testing. The content of the testing procedure regarding CSP filter capabilities and description will include the following documents:

- Description of equipment and process (including photos, engineering, construction and scientific concepts).
- Description of performance range, applications and inactivation capabilities of the disinfection properties relative to existing equipment.

The following operational details shall be included: the range of feed water quality suitable for treatment with the equipment, the upper limits for concentrations of micro-organisms that can be inactivated to concentrations below the manufacturer-specific level, level of operator skills required for successful use of the equipment.

3.5.2 Research performance method

The removal efficiency tests as described in paragraph 3.1 are executed in the Netherlands. But the tests will also be carried out in the three countries of origin (phase 2 of the CSP filter project). Also for this purpose a clear documentation of the research method, detailed filter descriptions and influent water characteristics are of paramount importance, the latter since the natural water sources in the countries of origin will highly differ what must not affect the outcome of the tests.

3.5.3 Testing protocol

Currently the CSP filters are tested in the factory by measuring the flow rate only. When the flow rate is between 1 and 2 litres/hour the filter is sold. In practice this method is not always reliable and a more secure testing protocol would be useful. Creating a testing protocol is in line with the investigations regarding the material characteristics.

3.6 Time schedule

The planning of this Master Thesis is spread over two phases. During the first phase the filters from the different production locations will be tested for a long period. The tests will mainly concentrate on LRV and the effects of colloidal silver.
The second phase of the research concerns the LRV of different batches from one specific production unit, the physical material characteristics, the flow rate and O&M (Operation and Maintenance). The number of weeks to be spent on these topics is given in Appendix A.
Information will be continually collected during the total length of this research project. Several weeks have been reserved for processing this information. The final period of the project will be used for report writing and the presentation of this Master Thesis at the Delft University of Technology.

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Appendix A: Time Schedule

Calendar weeks	46	47	48	49	50	51	52	1	2	3	4	5	6	7	8 to 20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
Master thesis weeks	1	2	3	4	5	6	7	8	9	10	11	12	13	14	BENIN	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Meeting with committee																													
Meeting with experts																													
Literature study																													
Set-up of filters in lab																													
Testing of filters various production locations																													
Additional research to role of silver																													
Flow rate variations																													
Material characteristics/testing protocol																													
Testing of filters from two different batches																													
Optionally operation test																													
Report																													
Presentation																													