SILVER IMPREGNATED CERAMIC WATER FILTER

Flowrate versus the removal efficiency of pathogens

S.C. Bloem - Delft University of Technology, Faculty of Applied Sciences – May 2008

Name	Sophie Bloem
Telephone	0031641554290
E-mail	S.C.Bloem@tnw.tudelft.nl
University	Delft University of Technology
Faculty:	Faculty of Applied Sciences
Study number	1108867

Date report	May 2008
Course	Research Internship Chemical Engineering (CH3701)

Committee:

Michael L. Sampson	Country Director Resource Development International - Cambodia
Prof. dr. ir. M.C.M. van Loosdrecht	Delft University of Technology Faculty of Applied Sciences Environmental Biotechnology
Ir. D. van Halem	Delft University of Technology Faculty of Civil Engineering and Geosciences Sanitary Engineering Section

SILVER IMPREGNATED CERAMIC WATER FILTER

Flowrate versus the removal efficiency of pathogens

This study is executed in cooperation with:

Resource Development International
Royal Brick Road
Kean Svay, Kandal
Cambodia

Aqua for All
Postbus 1072
3430 BB Nieuwegein
www.aquaforall.nl

Practica Foundation
Maerten Trompstraat 31
2628 RC Delft
www.practicafoundation.nl

Het Waterlaboratorium
J.W. Lucasweg 2
2031 BE Haarlem
www.hetwaterlaboratorium.nl

Kiwa Water Research
Groningerhaven 7
3433 PE Nieuwegein
www.kiwa.nl

Waterlaboratorium Noord
Rijksstraatweg 85
9756 AD Glimmen
www.wln.nl

ABSTRACT

An estimated 1.1 billion people world wide lack access to safe drinking water. Short time solutions to improve access to safe drinking water are House Water Treatment (HWT) systems. The development of HWT systems is increasing the last decades. The silver impregnated Ceramic Water Filter is one of those HWT systems. Source water is poured into the filter and is filtered through the ceramics. Source waters (rain, lake, tap etc.) are often contaminated with pathogens (bacteria, viruses and protozoa). The filtered water, greatly reduced in pathogens, drips in the receptacle and can be tapped from this receptacle by the user. In Cambodia, a 46% reduction in diarrheal diseases of users versus non-users of the filter was determined.

Potters for Peace introduced this filter in 1998 and these filters are now produced in 11 developing countries. One of those countries is Cambodia. Resource Development International – Cambodia (RDI-C) produces these filters since 2003. A research internship of three months is done at the filter factory of RDI-C.

The aimed flowrate of the CWF is between 1-3 L/h. The flowrates of these filters decrease over time as a result of clogging. Often they end as low as 0.5 L/h, which is too low to supply a family of clean drinking water. This low discharge rate is the main deficiency of the CWF. These low flowrates are worrying as a reliable HWT system should not only produce safe water, but also sufficient water.

In this research the flowrates of the CWF are increased by increasing the amount of rice husks or the amount of laterite added to the clay mixture. In total 14 filters were selected with initial flowrates ranging from 1.66 L/h to 7.56 L/h. Seven of the 14 filters were impregnated with a silver nitrate solution. The selected filters were tested for a period of one month on their flowrate and their ability to remove bacteria and viruses. After 400 liter of throughput the flowrates of the filters without silver decreased 6 to 17% compared to their initial flowrate. The flowrates of the filters with silver returned after an initial high increase to their initial flowrates (0.02% decrease to 0.3% increase). No faster decline was seen for filters with initial higher flowrates. No significant difference was seen between flowrate and removal of bacteria and viruses for filters with and without silver. The filters impregnated with silver had much higher Log Reduction Values (LRV) for *E.coli* then the filters without silver. Filters without silver had a mean LRV of 2.4 after 370 liter throughput. Filters impregnated with silver had a mean LRV of 7.2 (and might even be higher) after 330L throughput. Filters without silver had biofilm formation on the ceramic filter and in the plastic receptacle. No biofilm formation was seen for filters impregnated silver. The removal of viruses by the CWF with and without silver was more or the less the same. All 14 filters had a lower LRV for viruses then 0.4 after 370 liter throughput. This is low compared to other values in literature. Filters with increased laterite did not show higher LRV for viruses.

One month of intensive testing was done, but for a filter which must be used for at least two years, this is not long enough. Therefore this researched is continued at RDI-C. Depending on the results, this project will be continued for at least a year.

During this internship the reliability of the material (the clay) of the Ceramic Water Filter was examined. The clay consists of bricks, laterite, water and rice husks. Concluded is that the mixing of the clay is homogenous, and that separate batches and firing curves are comparable.

CONTENTS

1. INTRODUCTION

1.1 General

1.1 billion people worldwide lack access to improved drinking water. Moreover, 4% of all deaths and 5.7% of global disease burden are attributable to inadequate water, sanitation and hygiene including diarrheal diseases and other water related diseases. One of the Millenium Development Goals is to halve the proportion of people without access to safe drinking water by 2015. Because conventional piped water systems providing people with safe water are probably some decades away, short time solutions have to be found. Treating drinking water at household level, Household Water Treatment (HWT) systems also called or point of use (POU) treatment is one of those solutions. More and more POU are developed the last decennia. Examples are the biosand filter, the family lifestraw and the silver impregnated Ceramic Water Filter (CWF).

Potters for Peace started introducing the CWF in developing countries since 1998. They started in Nicaragua and the CWF is now produced in 11 developing countries. One of those developing countries is Cambodia.

In Cambodia, 66% of the people do not have access to safe drinking water. And 74% of Cambodian deaths is caused by waterborne diseases (RDI, 2008). The definition of waterborne diseases is: ”Diseases that arises from infected water and is transmitted when the water is used for drinking or cooking”. These arise from the contamination of water by human or animal faeces or urine infected by pathogenic viruses, bacteria, protozoa or other parasites, which are directly transmitted when the water is drunk or used in the preparation of food. All waterborn diseases can be water-washed diseases as well. Examples of waterborne diseases are cholera, thyphoid, hepatitis and diarrheal diseases. The majority of these deaths associated with diarrhea are among children under 5. They are more susceptible to the effects of malnutrition, dehydration, or other secondary effects associated with these infections. Recent field research in Cambodia showed that with the use of the CWF a 46% reduction in diarrheal disease is obtained (Brown, 2006).
In Cambodia there are three production location of the CWF. The filters are produced by the Cambodian Red Cross (CRC), International Development Enterprises - Cambodia (IDE-C) and Resource Development International – Cambodia (RDI-C). This research internship is done in collaboration and at the production location of RDI-C.

The CWF can be seen in Figure 1.1.

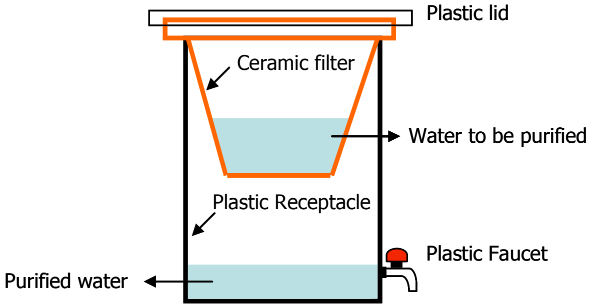


Figure 1.1: Ceramic Water Filter

How does this filter work? Source water (rain, lake, tap etc.) is poured into the filter and is filtered through the ceramics. Only source waters low in arsenic must be used as the CWF does not remove arsenic from the water. Source waters in Cambodia are often contaminated with pathogens (bacteria, viruses and protozoa). The filtered water, greatly reduced in pathogens, drips in the receptacle and can be tapped from this receptacle by the user. The working of the filters consist of two mechanisms:

screening of pathogens and the working of silver as a biocide. Details of these mechanisms are explained in Chapter 2.

1.2 Problem description

This research internships consist of two separate subjects. Because they are not directly related, they are handled separately throughout this report.

1.2.1 Flowrate versus removal of pathogens

Van Halem (2006) concluded that the low discharge rate is the main deficiency of the CWF. After 12 weeks of testing all filters had a flowrate lower than 0.5L/h, which is too low to supply a family of clean drinking water. Van Halem (2007) says that these low flowrates are worrying as a reliable HWT system should not only produce safe water, but also sufficient water. CWF with higher flowrates would be favorable. Van Halem (2007a) proposed the following curve (Figure 1.2):

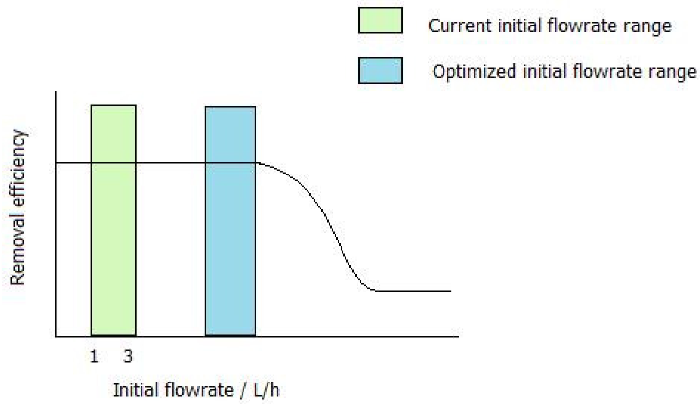


Figure 1.2: Possible curve of removal efficiency versus initial flowrate

Filters with higher flowrate have to posses the same removal efficiency. Therefore the range of the optimized flowrate is showed before the drop in removal efficiency. Secondly, the filters with higher flowrates have to keep these higher flowrates over time. The problem of the CWF is that the flowrate decreases in time. Starting with an initial flowrate of 2 L/h, the discharge rate was only 0.5 L/h after 12 weeks. A initial higher flowrate will decrease as well as a results of clogging by dirt particles. But will an initially higher flowrate of a filter stay higher over time then an initially lower flowrate?
Latagne (2001) showed that an initial higher flowrate ended after one year in a lower flowrate than a filter started with an initial lower flowrate.

In this research part filters with an increased flowrate are produced by increasing the amount of rice husks or laterite. The removal of pathogens (bacteria and viruses) and the flowrate in throughput is measured.

1.2.2 Homogenous mixing

In this part the reliability of the material of the Ceramic Water Filter is examined. There is a possibility that the mixing is incomplete, resulting in a non-homogeneous mixture. Because of this non-homogeneous mixture the CWF are not completely reproducible. There are differences for example in porosity, resulting in a different throughput of the water and a possible reduced microbiological efficiency. The consistency of the CWF material is examined with the purpose to check if the mixing is complete.

1.3 Outline

This report starts with a Theory study. In this chapter the removal mechanisms of pathogens of the CWF are described in detail. Some results of previous researches are shown as well. Finally the flowrate through the filter is discussed. The third chapter describes the production of the CWF in some more detail. Next to this, this chapter deals with the experimental parts of both research subjects: flowrate versus removal and the homogenous mixing. The results are shown and discussed in Chapter 4. The report is ended with a conclusion (Chapter 5). In this conclusion the most important results and conclusions of this internship research are summarized.

2. THEORY STUDY

Before starting and writing the internship research proposal (proposal can be found in Appendix A), a theory study was done. In this chapter the water purifying mechanisms of the CWF are discussed: the mechanism of screening and the working of silver and laterite as a biocide. Some removal efficiency numbers regarding to viruses and bacteria determined by previous studies are mentioned. Secondly the flowrate of the CWF is discussed. The mathematical function of the flowrate is derived in earlier reports by Eriksen (Latagne, 2001) and by van Halem (Halem, 2006) and will be repeated at the end of this Chapter.

2.1 Mechanisms of CWF

The working of the CWF mainly consists of two parts: the mechanism of screening and the working of silver as a biocide. Since 2005, RDI adds laterite, a soil containing iron oxide, to the clay. Laterite is said to bind and inactivate viruses. The screening mechanism and the working of silver and laterite are set aside below.

2.1.1 The screening mechanism and material characteristics

The phenomenon that particles can or cannot pass a filter determined by their size is called screening. The effective pore size of a filter determines the largest diameter of a particle that can pass through the filter. Therefore, when looking at water purifying filters, the size of the pathogens is an interesting parameter. And secondly, because the (effective) pore size determines what is retained and what not, the pore size is an interesting parameter as well. In Table 2.1 the sizes of bacteria, viruses and protozoa are summarized.

Table 2.1: Sizes of pathogens

Pathogen	Size
Virus (MS2)	25 nm
Bacteria (E.coli)	1 - 3 μm
Protozoa	1.5 μm

Because of the size of bacteria and protozoa, Potters For Peace (PFP) aimed for a pore size of 1 μm. Viruses are too small to be screened by this pore size.

Studies were done to determine the actual pore size of the CWF. Industrial Analytical Service, Inc. (IAS) investigated a CWF (manufactured by Potters For Peace) with the Scanning Electron Microscope (SEM) together with x-ray elemental analysis. Silicon, followed by oxygen and alumina were the main components of the filter. No silver was detected, because the concentration is too low to detect by x-ray. The filter was not uniform, cracks and spaces were detected by the SEM. Cracks had a length of 150 μm, spaces a length of 500 μm. The pore size determined by the SEM varied from 0.6 to 3 μm, which is in the range of the aimed 1 μm pore size by Potters for Peace (PFP). The spaces are probably the results of the pores created by the burn out material. The burn out material in the CWF are rice husks. Bostic (2008) scanned a piece of a CWF manufactured in Cambodia with a synchrotron. The synchrotron showed pores in the range of 1 micron.

Van Halem (2006) measured physical filter characteristics of CWF's manufactured in different countries (Cambodia, Ghana and Nicaragua). The effective pore size, porosity and the surface area of the CWF were measured by mercury intrusion porosity tests. The mean effective pore size measured was 40 μm. The porosity of the different filters ranged from 37% (Nicaragua) to 43% (Cambodia). The calculated pore area without silver was about 7.8 m^2/g. A surface area of 0.7 – 1.2 m^2/g was measured for filters impregnated with silver. Tortuosity is a measure for the actual length of a pore towards the thickness of the filter material. Measurements of van Halem showed that the filters were very tortuous.

Van Halem studied filters with and without silver. Because filters without silver, having a mean effective pore size 40 μm, which is larger than most pathogenic micro organism, removed bacteria over 99,99 %, other mechanisms besides screening were proposed. The other mechanisms proposed were: sedimentation, diffusion, inertia, turbulence and adsorption. A high surface area (result of high tortuosity) contribute to the mechanism of adsorption, diffusion and sedimentation.

2.1.2 Silver as a biocide

Silver is used as a biocide for centuries. Aristotle for example advised Alexander the Great to store boiled water in silver vessels to prevent waterborne diseases.

Silver is known to have an oligodynamic effect. This means that the effect of silver is noticeable when very small amounts are present. Three main mechanism of silver for the inactivation of bacteria are known (Russel, 1994): reaction of silver with a thiol groups in bacterial cells, the induction of a structural change in bacterial cell membrane by silver and the interaction of silver with nucleic acids.

The only known health effect of silver is Argyria. Agryria causes bluis-grey coloring of the skin, which starts in the eye and the fingertips (Latagne, 2001). These condition are irreversible and non-cancer causing. The maximum amount of silver in drinking water is 0.1 mg/L determined by the World Health Organization (WHO). Over a period of 70 years this gives the half of the human no adverse exposition limit (NOAEL).

In most of the CWF producing countries the filters are impregnated with a solution of colloidal silver. Colloidal silver solution is a solution with particles of at least 10^{-6} to 10^{-9} m. At RDI a silver nitrate solution is used to impregnate the filters. Raman spectroscopy was executed for dried solution of colloidal silver and silver nitrate (Kocar, 2006). The results showed that silver precipitated out of the silver nitrate solution and had more or the less the same size as colloidal silver from the colloidal silver solution. The data can be found in Appendix B. The advantage of using silver nitrate is that it is cheaper and it can be imported from China.

The amount of silver painted on a filter at RDI is about 70 mg (of which 1/3 is painted on the outside and 2/3 is painted on the inside). The amount silver painted on filters at other CWF factories is about the same.

Recently a piece of a CWF produced at RDI was scanned by a synchrotron (Bostic, 2008) and showed silver particles throughout the whole filter. This data is interesting as it showed that the impregnation of silver by a brush is enough to impregnate the silver throughout the whole filter.

The aimed flowrate of a CWF was originally determined by PFP to be 1-2 L/h. This flowrate was originally based on Microdyne, a colloidal silver solution. The Microdyne directions for drinking water purifications was to add one drop (10 ml) of 0.32 wt% silver solution to 2L of water and wait for 20 minutes. Based on this information, Ron Riviera, founder of PFP, calculated that 2 liters of water should at least have a residence time with the filter of 20 minutes. He multiplied this by a factor of three, because water does not remain in the filter. PFP now uses 2 ml of 3.2 wt% silver per filter (Latagne, 2001). This is about 64 mg of silver per filter.

The definition of a biocide is that it is able to destroy living organism. The mechanism of the inactivation of bacteria by silver is known. But the mechanism of virus inactivation by silver has still not been satisfactorily satisfied. Butkus (2004) said that given contact time in the order of hours, silver has been shown somewhat effective as disinfectant against coliforms *and viruses*. And also Brown (2004) showed that silver seemed to be responsible for virus reduction. By adding silver to Nica clay, the LRV increased from 0 to 5.11 for the removal of MS2. But van Halem (2007) showed interesting different results. She compared filters with and without silver. The filters without silver did a better job in removing viruses, this might be related to the higher surface are as mentioned in Section 2.1.1.

The increased removal of pathogens by filters impregnated with silver is proven by a number of studies (van Halem, 2006) and (Latagne, 2001). Some of those numbers of these studies are summarized in Table 2.2.

Table 2.2: Results of previous studies on microbiological effectiveness of CWF

Filter	Pathogen	Water	LRV	Reference
CWF (Cambodia, silver)	*E.coli* K12	Canal water	5	Van Halem (2007)
CWF (Cambodia, silver)	MS2	Canal water	0.9-1.75	Van Halem (2007)
CWF (Nicaragua, silver)	*E.coli* K12	Canal water	6.6	Van Halem (2007)
CWF (Nicaragua, silver)	MS2	Canal water	0.57-1.07	Van Halem (2007)
CWF (Nicaragua, no silver)	*E.coli* K12	Canal water	4	Van Halem (2007)
CWF (Nicaragua, no silver)	MS2	Canal water	1.25-2.07	Van Halem (2007)
CWF (Cambodia, no silver)	*E.coli* CN13	Surface water	2.4	Brown (2007)
CWF (Cambodia, no silver)	MS2	Surface water	1.9	Brown (2007)
CWF (Cambodia, silver)	*E.coli* CN13	Surface water	2.4	Brown (2007)
CWF (Cambodia, silver)	MS2	Surface water	1.7	Brown (2007)
CWF (Cambodia, silver, laterite)	*E.coli* CN13	Surface water	2.2	Brown (2007)
CWF (Cambodia, silver, laterite)	MS2	Surface water	1.3	Brown (2007)

It is interesting that within the results of Brown (2007) there is no significant difference between the CWF with and without silver. Although the results of Van Halem show a significant difference. It might be that the source of silver (colloidal vs. silver nitrate) makes a difference in the removal efficiency. This subject is further discussed in Chapter 4.

2.1.2 Laterite as a biocide

Viruses are very small and therefore not removed by the screening mechanism. Virus reduction is difficult and therefore a barrier to the effectiveness of the filter.
RDI adds laterite to their clay mixture. Laterite, which contains iron oxide, is said to improve the removal of viruses. Although, as can be seen in Table 2.1, there was no significant difference between the filters with and without laterite for the removal of viruses (and bacteria). But previous research done at RDI showed that adding laterite to the clay mixture increased the removal of viruses. Virus inactivation appears to be associated with the strength of electrostatic attraction due to virus/surface charge differential, but it might be due to other factors. Brown and Sobsey (year unknown) did lab scale experiments to the removal of viruses with different types of soils containing metal oxides. They crushed ceramic with goethite (contains iron oxide) and shaked phage spiked water for 15 minutes. LRV's as high as 9 for virus removal were obtained. Concluded was that metal-oxide enhanced ceramic surfaces can capture and inactivate viruses. A filter containing yellow iron oxyhydroxides was tested continuous. In time the LRV for the removal of viruses decreased from 6.5 to 1. After cleaning the LRV increased to 3.5. Concluded was that by scrubbing the filter the active sites are unblocked. Users are often afraid to scrub there filter, mainly because they believe that they will remove the silver. But as shown by Bostic (2008) silver is impregnated throughout the whole filter. By scrubbing the filter, the active sites are unclogged and the efficiency of the filter is enhanced.

Another document of Brown (2004) concludes that iron oxide is not responsible for virus removal. Raw iron oxide showed LRV lower than 1. But another oxide, Aluminum oxide, might be interesting as it showed LRV higher than 7.76.

Youwen (2005) showed that zerovalent iron removed and inactivated viruses. The initial LRV was 4 and even increased to 5. This increased value might be due to continuous formation of new iron (oxyhydr)oxides (corrosion) which serve as sorption site. The mechanism is not fully understood but suggested is that virus particles adsorb to iron (oxyhydr)oxide through electrostatic attraction and followed by inactivation. The attractive force disintegrate the viruses and thereby inactivates this pathogen.

2.2 Flowrate

The CWF's always contain a burn out material. The burn out material is an organic material such as saw dust, recycled paper or rice husks. In the CWF manufactured in Cambodia the burn out material used is rice husks. Rice husks are added to the clay and during the firing of the filters the rice husks are burned out the pot, leaving empty spaces behind. These pores are responsible for the increased flowrate of the filter. When no rice husk would be added, the filters would be like a flower pot and only very little permeable.
In general there are three types of pores: isolated pores, interconnected pores and open ended pores. Van Halem (2006) mentioned that only the interconnected pores contribute (continuous) to the flowrate. According to Sampson (2008), all three contribute to the flowrate. This, because the ceramic material between the pores, created by rice husks, is porous as well. If this was completely solid, isolated pores would not contribute to the flowrate. The diffusion of water through isolated pores is higher than when there are no pores, or only ceramic material. More pores will result in overall higher flowrate. This is schematically depicted in Figure 2.1.

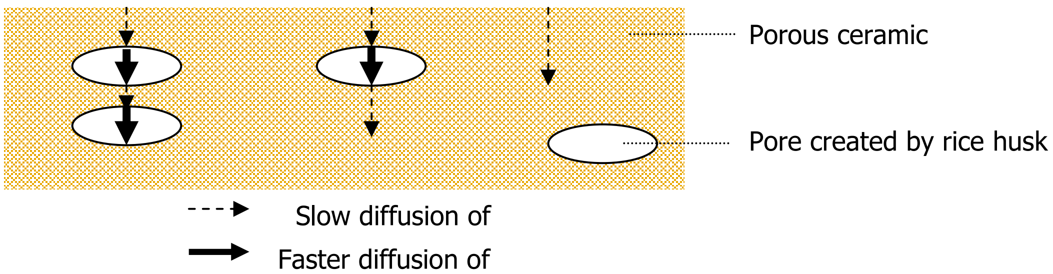


Figure 2.1: Flow through porous ceramics

In this research (see Experimental Part), the amount of rice husks added to the clay is increased. By increasing the amount of burn out material the number of pores (overall porosity) is increased together with the flowrate.

Porosity and permeability are two different concepts. Porosity is a number between 0 and 1 or a percentage. This number tells how much of the volume are voids. The permeability is a measure of the ease of which a fluid flows through a material. A material might be very porous, but if the if the material between the pores is not permeable and all pores are isolated, the intrinsic permeability is zero.

The mathematical function of the flowrate through a CWF is derived by Van Halem (2007) and can be found below. The flowrate through a filter is based on Darcy's law [2.1], which describes laminar flow through a porous media with linear relation. Darcy's law is used to determine the flow through the bottom [2.2] and through the walls [2.3]. If these two are combined, the total flow through the filter is obtained [2.4]. The model corresponds with experimental data.

$$Q_{Darcy} = k\frac{Ah}{t} \quad [2.1]$$

$$Q_{filterbottom} = \frac{k}{t_b}\pi r_2^2 h_w \quad [2.2]$$

$$Q_{filterwall} = \frac{k}{t_f}2\pi(\frac{(r_1 - r_2)}{6L}h_w^3 + \frac{1}{2}r_2 h_w^2) \quad [2.3]$$

$$Q_{filter} = \frac{k}{t_f}2\pi(\frac{(r_1 - r_2)}{6L}h_w^3 + \frac{1}{2}r_2 h_w^2) + \frac{k}{t_b}\pi r_2^2 h_w \quad [2.4]$$

Where,

Q = filter discharge (m^3/s)
k = hydraulic conductivity (m/s)
A = surface area in (m^2)
h = water level in filter (m)
t = thickness of filter material (m)
t_b = thickness of bottom of filter (m)
t_w = thickness of wall of filter (m)
L = slant height (m)
h_w = water level in the filter (m)
r_1 = radius at top of the filter (m)
r_1 = radius at bottom of the filter (m)

The hydraulic conductivity is determined by the intrinsic permeability [2.5]

$$k = \frac{\kappa\gamma}{\mu} \quad [2.5]$$

Where,

κ = intrinsic permeability (m^2)
μ = dynamic viscosity of water (Pa.s)
γ = unit weight of water (N/m^3)

The discharge rate through the filter is important. First of all because it has to be high enough to supply the family with clean water. But secondly, the contact time (or residence time) of the water to be purified with the silver has to be long enough to make sure all pathogens are killed. As mentioned in Section 2.1.2, the aimed flowrate for the filter, which is 1-2 L/h, was based on one drop Microdyne for 20 minutes in 2 liters of water to be purified. This was a rough calculation to determine such an important parameter. Was the calculation accurate enough to determine that the flowrate must be 1-2 L/h?

The residence time can be calculated by:

$$\tau = \frac{V}{Q} \quad [2.6]$$

Where,

T = residence time (h)
V = volume (m^3)
Q = discharge rate (m^3/h)

As can be seen in [2.6], the residence time of the water in the filter is determined by the volume divided by the discharge rate. Notice that V and Q will change with the water head.
The residence time of the water *in* the filter material is determined by the porosity of the filter. The higher the porosity, the higher the volume of water storage *in* the filter (walls and bottom). But as said before, by increasing the overall porosity, the discharge rate will increase as well. Experiments must be done towards these relations. Probably, more accurate mathematical derivation can be done as well, but this was not beyond the scope of the project.

Another danger is that when increasing the amount of rice husks this has a higher change to result in interconnected pores. Interconnected pores of rice husks are large, diameter 0.5 to 1 mm, and no screening will take place as all the pathogens are smaller then the pore diameter. Next to this, the filter might clog quicker and result in an even lower flowrate after several months. This phenomenon was seen earlier, an initial flowrate of 3.5 L/day ended in a flowrate of 2.14 L/day after a year (34% reduction). The filter with an initial flowrate of 5.5 L/day had a flowrate of 1.97 L/day (64% reduction) after a year (Latagne, 2001).

3. EXPERIMENTAL PART

As described in the problem description, this internship research exists of two separate research parts. In this chapter, the experimental work of both research parts is described.

3.1 Experimental part I: Flowrate vs. removal of pathogens

Before starting the experiments a field research was done. This chapter starts with a short note on the field research. Secondly a summary of the different steps of the fabrication process of the CWF are set aside. Next, the recipes of the filters with increased flowrate together their selection is described, followed by the spiking procedure and experimental set-up. The chapter ends with the methods used for measuring *E.coli* and *MS2* (the indicator organism), the flowrate and the silver concentration in the output.

3.1.1 Field research

Before starting the research a field study was done. Ten households using a CWF were visited. Five households that were using the filter for less than a year (3 to 5 months) and five households that were using their filter for more then one year (2 to 3 years) were selected. It was tried to visit households that use different source waters: lake water, rain water, tap water or a combination.

Although ten households is not enough to draw serious conclusions, it is a good indication of the range of flowrates. Next to this, it was useful to talk with users of the CWF in the field. In Appendix C the enquiry of the field research can be found.

3.1.2 Fabrication of the Ceramic Water Filter

In this section the fabrication process of the production of the CWF is shortly described. A more detailed description of the CWF process can be found in the Handbook of Ceramic Water Filter (Hagan, 2008).

The nine general steps in the production of a CWF are:

1. Preparing the raw material (bricks, rice husks, laterite and water)
2. Mixing the raw material into a clay
3. Making blocks and press them into filters
4. ‘Reshaping’ and labeling
5. Drying
6. Firing
7. Testing on flowrate (first saturate, then test)
8. Impregnate with silver
9. Make the total package (receptacle + filter + tap)

Per step remarks are made.

1. *Preparing the raw material*
   The following raw materials are used for the production of the CWF.
- Powder of unfired bricks 30 kg (73,5%)
- Powder of laterite 2 kg (5%)
- Rice husks 8,8 kg (21,5%)
- Water 12,5 kg

The unfired bricks form the base clay material. Laterite is added as a raw material because it contains iron oxide and this is said to bind/inactivate viruses. Rice husk is the burn out material of the CWF. When fired (see step 6), rice husks burn out of the material and create pores that increase the total porosity of the material. Water is added to make it possible to press the filters in to the right shape.

2. *Mixing the raw material into a clay*
   The mixing of the raw material is done with a timer (light). Water is fed automatically; it is possible to add more water when needed. The amount of raw materials mentioned at step 1 (one batch) is fed to one mixer.
3. *Making blocks and press them into filters*
   Blocks of about 8,2 kg are made. Out of one batch six filters are produced. A hydraulic press presses the clay into the filter shape. Excess of clay is pressed out of the mould.
4. *'Reshaping' and labeling*
   The rim and large cracks are repaired / smoothed by women. The CWF holds their original shape. After a few hours the filters are labeled (date, logo and number).
5. *Drying*
   The CWF's are dried for 7 -15 days during the dry season and for 15 - 18 days during the wet season.
6. *Firing*
   Dried filters are placed in a kiln. The kiln is first fired up to 100°C, this is measured with a pyrometer inside the kiln. Next, the kiln is fired up to 830°C. At this temperature the first Orton cone will collapse to indicate that they are close to the desired temperature, which is 866°C. When this second cone collapse, the fuel (wood) that is still in the kiln is removed and the doors are closed. After 9 hours the doors are opened and the kiln is cooled down for 24h.
   The following phenomena take place during heating up:

Up to 100°C	Excess of water is removed
100°C - 200°C	The physically bounded water is released
200°C - 450°C	The rice husks burn out, pores are created which will increases the overall porosity
450°C - 600°C	Dehydration of the clay as chemically bounded water (OH in mineral structures)
600°C - 866°C	Start sintering

7. *Testing on flowrate*
   After firing the filters are tested. They are soaked under water for minimal 3 hours. The flowrates of the filters are tested with a T-piece. Filters are filled up to the rim and after 60 minutes the T-piece (with marked liter lines) is hung in the filter. It is possible to read the number of liters filtered through. The filters within the range 1.5 – 3 L/h are accepted. When placing the filters in the soak bath, every filter is inspected for cracks or irregularities at the rim.
8. *Impregnate with silver*
   Filters are painted with silver: a solution of silver nitrate (0,23 g/L) is used for this purpose. 300 ml of this solution is painted on each CWF (200 ml inside filter, 100 ml outside filter, a marked cup is used). The working of silver as a biocide is described in Chapter 2.
9. *Make the total package*
   The total package consists of a receptacle, a lid, a plastic ring, the filter, a brush, a tap and an instruction flyer.

3.1.3 Production of filters with different flowrates

Filters with different flowrates were produced by increasing the amount of rice husk *or* increasing the amount of laterite. As rice husks being the burn out material, it makes sense that by increasing the amount of rice husks the total number of pores and overall porosity increases. In this case, by increasing the total porosity, the flowrate is increased (see further Chapter 2).

Laterite is said to change the structure of the filter. It makes the filter less strong and more porous.
The recipes for the filters with increased flowrate can be found in Table 3.1 and 3.2. The R2L is the standard recipe for the filters. 'R' indicates an increase of rice husk. 'LA' indicates an increase of laterite. The number after the letter indicates the aimed flowrate. R4L, for example, is a filter with

increased rice husks with an aimed flowrate of 4 L/h. LA5L for example, is a filter with increased laterite with an aimed flowrate of 5 L/h. The first attempt to increase the flowrate of the CWF failed. The recipes together with the measured flowrates of this first attempt can be found in Appendix D.

Table 3.1: Recipes with increased rice husks

Raw materials	R2L Mass / kg	R4L Mass / kg	R5L Mass / kg	R6L Mass / kg
Bricks	30	30	30	30
Laterite	2	2	2	2
Rice husk	*8,8*	*10*	*11*	*12*
Water	12,5	12,50	12,5	12,5
Total	53,3	54,50	55,5	56,5

Table 3.2: Recipes with increased laterite

Raw materials	R2L Mass / kg	LA4L Mass / kg	LA5L Mass / kg	LA6L Mass / kg
Bricks	30	30	30	30
Laterite	*2*	*4*	*6*	*8*
Rice husk	8,8	8,8	8,8	8,8
Water	12,5	12,5	12,5	12,5
Total	53,3	55,30	57,3	59,3

3.1.4 Selection of filters to be tested

After the firing of the filters with increased flowrate (step 6), the filters were soaked overnight and tested on the flowrate. The measured flowrates of all filters produced can be found in Appendix D. The initial plan was to select two filters of each category (R2L, R4L, R5L, R6L, LA4L, LA5L, LA6L). One would be painted with silver and the other one not. Because the flowrates of LA4L were still low, none of these filters were selected. Two more were selected of the LA6L batch.

Selected was on the appropriate flowrate and no cracks inside or outside.

The final selection of filters can be found below. An additional *S* indicates that this filter was painted with silver nitrate solution. The additional number is the identification of that certain filter (six filters were made out of every batch, numbered 1 to 6). For the filters of R2L standard filters out of the production line were taken.

R Increased rice husk, except R2L which is the standard filter
LA Increased laterite
X L Aimed flowrate X L/h
S Painted with silver
- Y Identification number Y of specific filter

Table 3.3: Selected filters to be tested

No silver	Silver
R2L- 8	R2LS - 3
R4L - 3	R4LS - 6
LA5L - 3	LA5LS - 5
R5L - 1	R5LS - 4
LA6L - 5	LA6LS -
R6L - 1	R6LS - 5
LA6L - 4	LA6LS - 1

3.1.5 Testing of the selected filters

The 14 selected filters were tested for one month. They were tested on *E.coli B* and *MS2* removal. Both *E.coli B* and *MS2* are indicator organism. The first one is an indicator organism for bacteria, the latter one is an indicator organism for viruses. The filters were loaded with 10L water in the morning and 10L in the evening. After every 30L throughput the filter was loaded with 10L water which contained a high number of the indicator organisms. More information regarding the spiking can be found in this Section 3.1.5.1. When the water was spiked, input and output samples of each filter were taken. The *E.coli* and the *MS2* of the input and the output of each filter was measured and therefore the Log Reduction Value (LRV) of the filters could be determined. The techniques used to measure bacteria and viruses are described in this Sections 3.1.5.2 and 3.1.5.3. Before taking samples the receptacles were emptied. The receptacles of the filters painted with silver were wiped with a clean paper because silver might accumulate to the wall.

Next to the removal of bacteria and viruses, the flowrate of the filters was measured. This was done after every 100L throughput. After every 150L throughput, the filter and the receptacle were cleaned using methods recommended by RDI (Appendix F.3). Of the filters painted with silver after every 100L throughput samples of the output were taken to measure the silver content in the effluent, because silver might leach out of the filter during use. The experimental set up can be found in Figure 3.1.

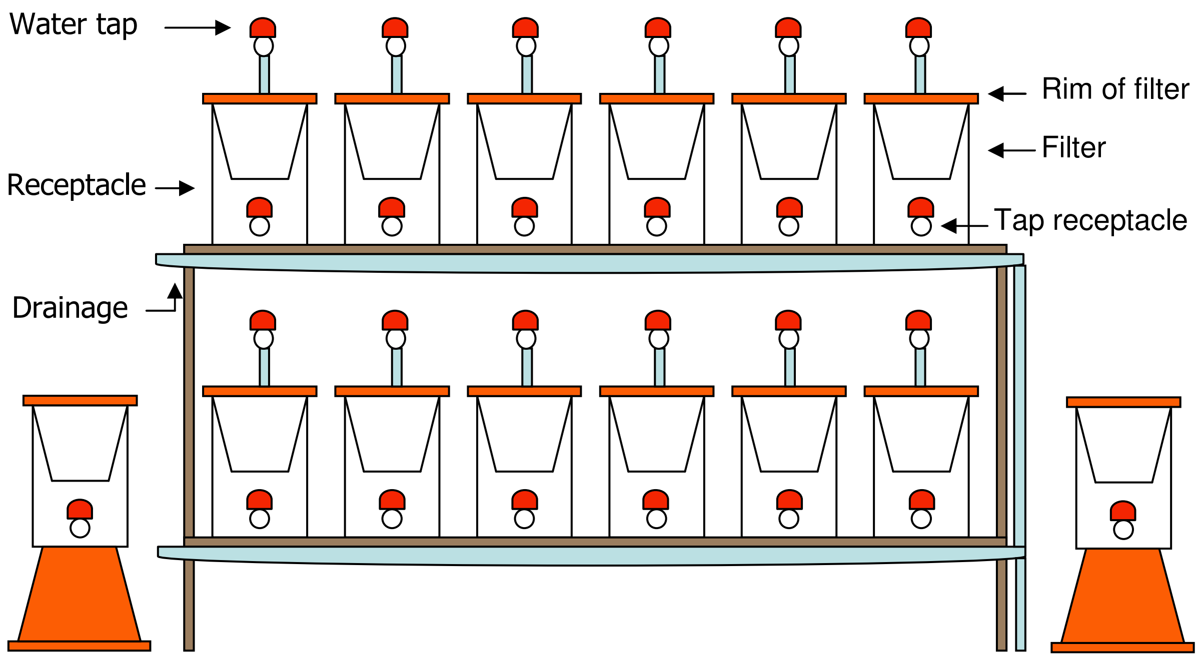


Figure 3.1: Schematic drawing of set-up

Because the testing of the filters is only done for one month, the testing will be continued by RDI. Monthly, RDI will send results of this research to the Netherlands. A document that describes the continuation of the project (a more detailed description of all experimental work) can be found in Appendix F. In Appendix E a schedule of the testing procedure for the first month can be found.

3.1.5.1 Spiking

Spiking of water before measuring was done to calculate the highest possible Log Reduction Value (LRV) of a filter. The river water filtered through the CWF is spiked with two indicator micro organism. *E.coli B* is used as an indicator for pathogenic bacteria. The water was spiked to a concentration of 10^3 – 10^5 coliforms forming units (cfu) per ml, regarding if the filter was painted with silver or not. *MS2* was used as an indicator for bacteriophages. The water was spiked to a concentration of 10^4 plaque forming units (pfu) per ml. How to dilute to get this number of cfu/ml and pfu/ml can be found in Appendix F.2.

Two times 100 ml containing 10^5 cfu/ml or 10^6 cfu/ml (depending if filters were painted with silver or not) and 10^6 pfu/ml was added to a tank with 20L of purified river water. This was mixed for 15 minutes and a sample was taken. The 20L was equally divided over two filters. Mixing took place in a separate water tank because when mixing it directly in the CWF painted with silver the indicator organism were reduced by contact with the silver painted in the inside of the filter. As a result, the influent sample (taken after mixing) would not be representative. Effluent samples were taken after 1 to 2 hours. Effluent samples of the filters painted with silver should not be taken after more than 1-2 hours. Silver might leach out of the filter and will (further) kill pathogens in the receptacle. This would result in a not-representative LRV for the filter.

3.1.5.2 E.coli membrane filtration

Membrane filtration is used to determine the *E.coli* concentration of the in and effluent samples of the filters. Samples were filtered through 47 mm diameter and 0,45 µm pore size cellulose ester filters of Millipore. The membranes were incubated on agar for 18h at 37 °C. Two different agars were used. The agar changed after two weeks, because RDI ran out of stock. Before changing the agars, same samples were compared by using the different agars. They gave similar results. *RAPID' E.coli 2 Agar* of BIO-RAD was used the first two weeks. The last two week *HiCrome E.coli Agar* of HIMEDIA was used. More information of the material used (agars, membrane filters) can be found in Appendix E.

Input samples were always diluted 10 to 100 times (depending on initial spiking) and 100 µl of the diluted sample was filtered through the membrane filter. Samples of 100 ml of the output from the filters *with* silver were filtered through the membrane filter, while only 1 ml going up to 10 ml was filtered from the filters without silver.

3.1.5.3 Viruses: Spot Titer

MS2 phages were enumerated on tryptic soy agar using the spot titer method. In the beginning *E.coli F-amp* was used as the Log Phage Host (LPH). The appropriate antibiotics for this bacteria is streptomycin/ampicillin (S/A). After 3 weeks *E.coli C3000* was used as LPH. The appropriate antibiotics for this bacteria is ampicillin. Nine drops of 0,01 ml were spotted on the agar in grid pattern which contained the host and the antibiotics. Plates were inverted and incubated for 18h at 37 °C. Plaques of the phages can be counted and pfu/ml can be calculated. A more detailed description of this spot titer method can be found in Appendix F.

3.1.5.4 Flowrate

Flowrates of the filters were measured by filling up the filter to the rim. Before measuring the receptacle was emptied. After 30 minutes the filter was taken out of the receptacle and the volume in the receptacle was measured. This flowrate measured is the maximum initial flowrate, because the flowrate is decreasing with declining head. More information about the flowrate can be found in Chapter 2.

3.1.5.5 Silver measurements

Silver measurements were done at Technical University of Delft using a Atomic Absorbance Spectroscope (AAS).

3.2 Experimental part II: Homogeneous mixing

In this section, the experimental work of the research to the reliability of the mixing of the clay of the CWF is described.

For three weeks long, every day two samples were taken from a batch after the mixing of the raw materials (unfired bricks, laterite and rice husks) with water. These samples were pressed in a plastic disc with an internal diameter of 8.8 cm and internal height of 1.3 cm. The samples were labeled and measured was the following:

- The weight of the discs (m_{disc})
- The weight of the clay in the discs, together with disc (m_{wet})
- Diameter of the disc (D_{disc})

Secondly, these discs containing the clay were placed outside for two days (temperature ~ 30C°); the samples were sun dried. In the normal process the CWF is dried for two weeks. Two days was enough for the samples to remove most of the excess water which is necessary for moulding the clay into the desired shape. After drying the following was measured:

- The weight including the disc (m_{dry})

Afterwards the plastic discs were removed and measured was:

- The weight of the clay ($m_{dry\_no\ disc}$)
- The diameter of the clay (D_{dry})

The dry shrinkage and the humidity can be determined with [3.1] and [3.2]:

$$\text{Dry shrinkage} = \frac{D_{disc} - D_{dry}}{D_{disc}} \bullet 100\% \qquad [3.1]$$

$$\text{Humidity} = \frac{m_{wet} - m_{dry}}{m_{wet}} \bullet 100\% \qquad [3.2]$$

The initial plan was to place the samples *in* a CWF which was fired in that kiln as well. Results showed that the samples in the filter did not got enough oxygen, therefore the dried clay samples were placed *next* to the filters in one of the production kilns.

After firing the clay samples, the following was measured:

- The weight of the samples m_{fired}
- The diameter D_{fired}
- The height H_{fired}

Weight reduction, fire shrinkage and total shrinkage can be determined with [3.3] to [3.5]:

$$\text{Weight reduction} = \frac{m_{dry} - m_{fired}}{m_{dry}} \bullet 100\% \qquad [3.3]$$

$$\text{Fire shrinkage} = \frac{D_{dry} - D_{fired}}{D_{dry}} \bullet 100\% \qquad [3.4]$$

$$\text{Total shrinkage} = \frac{D_{disc} - D_{fired}}{D_{disc}} \bullet 100\% \qquad [3.5]$$

Afterwards, the clay samples were soaked under water for 24h. The soaked samples were weighted (m_{water}) to determine the water uptake [3.6].

$$\text{Water uptake} = \frac{m_{water} - m_{fired}}{m_{fired}} \bullet 100\% \qquad [3.6]$$

The porosity of the samples was determined with the direct method. The density of water at 15 °C is 0.999 cm^3 / g. The porosity was calculate with [3.7]:

$$\text{Porosity} = \frac{m_{water} - m_{fired}}{V_{fired} * \rho_{water}} \bullet 100\% \qquad [3.7]$$

V_{fired}, the volume of the fired disc was calculated by [3.8]

$$V_{fired} = 0.5 * \pi * D_{fired}^2 * H_{fired} \qquad [3.8]$$

4. RESULTS AND DISCUSSION

In this chapter the results of both research parts will be discussed. The results of the field research is discussed in Section 4.1.1.

4.1 Flowrate versus removal of pathogens

In Section 4.1.1 the results of the field research are shown and discussed. Secondly, the results of the flowrate measurements versus throughput are shown. The removal of *E.coli* (bacteria) and *MS2* (viruses) by the filters with and without silver is discussed in Sections 4.1.4 and 4.1.5. In Section 4.1.6, additional observations are mentioned. This paragraph is ended with a discussion regarding the silver measurements with AAS.

4.1.1 Field research

Results of the field research are summarized in Table 4.1.

Table 4.1: Flowrate field research

No.	Family	No. of persons in household	Source water	Use	Flowrate/ (L/h)
1	Yin Sophary	5	Lake water	3 months	1,44
2	Om Noy	9	Lake water	3 months	2,36
3	Hem Vanny	7	Rain / well	4 months	2,1
4	Nhem Soknom	6	Tap	5 months	4,2
5	Koy Kouy	5	Rain	5 months	4,62
6	Seang Teng	4	Mix: rain & lake	2 years	1,04
7	Cheng Navin	10, had 2 filters (1CWF and 1 Korean)	Tap, before rain	2 years	2,28
8	San Samang	6	Rain	3 years	0,68
9	Sen Navy	6	Rain (1 year);lake (2 years)	3 years	0,68
10	Ou Simon	3	Rain	3 years	1

The answers of the different families are summarized and can be found in Appendix C.2. Some interesting results are mentioned here. But, as said before, a questionnaire with only ten households is not enough to draw solid conclusions. One of first things that is remarkable, is that filters that are longer in use have a lower flowrate. This is not strange, as the filter get clogged over time. Secondly, a difference can be seen in the type of source water. If we compare for example households no. 1 and 2 with 4 and 5 a difference in flowrate is observed. Households no. 1 and 2 use lake water as water source, while no. 4 and 5 use tap respectively rain water. Lake water is said to have a high turbidity (NTU), containing more larger particle that easily can block the pores of the filters. Another observation was that filters used for purifying lake water had a more black and dirty appearance.

Despite some of the low flowrates, all families said that the filter provided enough water for the whole family. When asking if it was enough for cooking as well only two families (no. 1 and 2) answered that it was not enough. Most families used the water from the filter only for drinking purposes because of habit. All families are happy with the filter and do not want a higher flowrate. The main reason was that they associate a high flowrate with bad purification: slow is good, fast is no good. A final interesting thing is that they do not (only 2 out of 10) clean the ceramic filter with a brush. They believe that when brushing, they will remove the silver. But as said in Chapter 2, the silver is impregnated throughout the whole filter and scrubbing is important to unclog active sites. RDI recently made a new clean schedule and had meetings with the educators of the filters to be in line with the message of cleaning.

All families said that the filter provided them with enough water. This is interesting, because when having a maximum flowrate of 0.68 L/h and the family consists of 6 persons it is impossible to provide (only for drinking purposes) 3-4 liters a person (WHO, 2005).

4.1.2 Challenge water

The water that was used for filling up the 14 filters was tested on pH, turbidity (NTU), and *E.coli*. The quality of this river water varied per day and data of two days are summarized in Table 4.2. The water was said to be river water, coming from a purification unit that mainly removed coarse particles.

Table 4.2: Challenge water

	19-mrt	24-mrt
pH	7,33	7,12
NTU	3,69	12,33
***E.coli* / cfu/100ml**	26	5

4.1.3 Flowrate versus throughput

For one month the flowrates of the 14 selected filters were measured. After every 100L throughput the flowrate was measured. The measured flowrates can be found in Table 4.3 and 4.4. It can be concluded that the second attempt to increase the flowrate of the filters by increasing the amount of rice husk or the amount of laterite was succeeded. It is interesting that for increasing the flowrate there is a certain threshold value of the amount that must be added to actually increase the flowrate. All initial flowrates of attempts 1 and 2 to increase the flowrate can be found in Appendix D.

Table 4.3: Flowrates of filters without silver

Throughput / L	R2L-8	R4L-3	LA5L-3	R5L-1	LA6L-5	R6L-1	LA6L-4
0	1,66	4,84	3,6	6,58	6,4	7,56	7,16
90	2,44	5,32	3,96	6,4	6	7,84	6,8
210	1,7	6,68	4,63	8,2	7,28	10	8,66
320	1,7	6,74	4,7	7,6	7,36	9	7,7
400	1,4	4,3	2,9	5,7	6	7	5,95

Table 4.4: Flowrates of filters with silver

Throughput / L	R2LS-3	R4LS-6	LA5LS-5	R5LS-4	LA6LS -	R6LS-5	LA6LS-1
0	1,84	5,04	3,3	5	4,64	7,16	5,14
90	2,66	7,7	4,9	7,4	7,54	8,8	6,84
200	2,56	7,88	5,14	6,62	6,96	7,86	5,82
310	3,6	8,1	6,5	7,7	8	9	7,6
400	1,9	5,7	4,3	4,9	5	6,1	4,7

The initial flowrates measured to select the filters were measured by a T-piece (Section 3.1.2) and are repeated in Table 4.5. When measuring these flowrates, none of the filters were impregnated with silver. With these values we can compare the influence of silver on the flowrate.

Table 4.5: Initial flowrate measured by T-piece

ID	Flowrate / L/h T-piece; no silver	Flowrate / L/h no silver	ID	Flowrate / L/h T-piece; no silver	Flowrate / L/h silver
R2L-8	-	1,66	**R2LS-3**	-	1,84
R4L-3	5	4,84	**R4LS-6**	5	5,04
LA5L-3	4,5	3,6	**LA5LS-5**	4	3,3
R5L-1	4,5	6,58	**R5LS-4**	4,6	5
LA6L-5	6	6,4	**LA6LS -**	6	4,64
R6L-1	7	7,56	**R6LS-5**	7	7,16
LA6L-4	7	7,16	**LA6LS-1**	6,8	5,14

The flowrates of the filters in columns 2 and 3 of Table 4.5 are not exactly the same, because of a different way of measuring. The flowrates in the second column are more accurate. In column 5 the flowrates of the filters *to be* painted can be found. In the sixth column flowrates of these filters after being paint with silver are depicted. 4 out of the 6 flowrates show a decrease and only 2 show a slightly increase. Probably silver initially clogs some pores. But the difference can also be explained by a different measuring technique. Extra evidence for 'the clogging theory' is that after 90L of throughput all flowrates of the with silver impregnated filters are increased (see Figure 4.2 and Table 4.7), while the flowrates for the filters without silver have lower increase.

In Figures 4.1 and Figure 4.2 the flowrate of the filters versus the throughput without and with silver can be seen. The black arrows indicate when the filters were cleaned. The red dotted line shows when there was no water in the filters (during weekends). Biofilm formation might be higher when the filter is empty and could have an influence on the flowrate and removal efficiency.

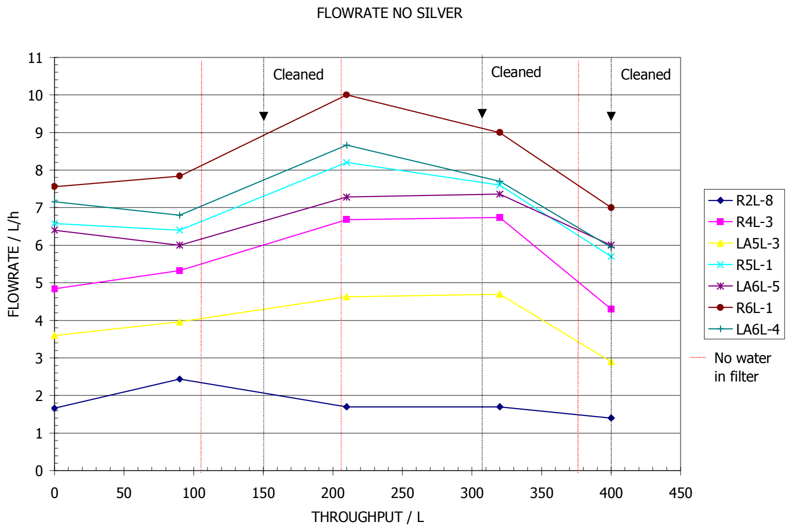


Figure 4.1: Throughput vs. flowrate for filters without silver

There does not seem to be a clear relation between cleaning and flowrate, or between biofilm formation and flowrate. As can be seen from Figure 4.1 the trend of the flowrate is the same for all filters except for R2L-8. All filters first increase, then decrease. It might be that they are stabilized now, or will even decrease further as result of clogging. As said in Chapter 3, the experiments are continued and results will be send to the Netherlands. In Table 4.6 the percentage increase/decrease from the initial flowrate can be seen for the filters without silver. There is no faster decline (till so far) of flowrates with an initial higher flowrate.

Table 4.6:Increase/decrease in percentages of filters without silver

	R2L-8	R4L-3	LA5L-3	R5L-1	LA6L-5	R6L-1	LA6L-4
in/decrease 0 - 90L / %	46,99	9,92	10,00	-2,74	-6,25	3,70	-5,03
in/decrease 0 - 210L / %	2,41	38,02	28,61	24,62	13,75	32,28	20,95
in/decrease 0 - 320L / %	2,41	39,26	30,56	15,50	15,00	19,05	7,54
in/decrease 0 - 400L / %	-15,66	-11,16	-19,44	-13,37	-6,25	-7,41	-16,90

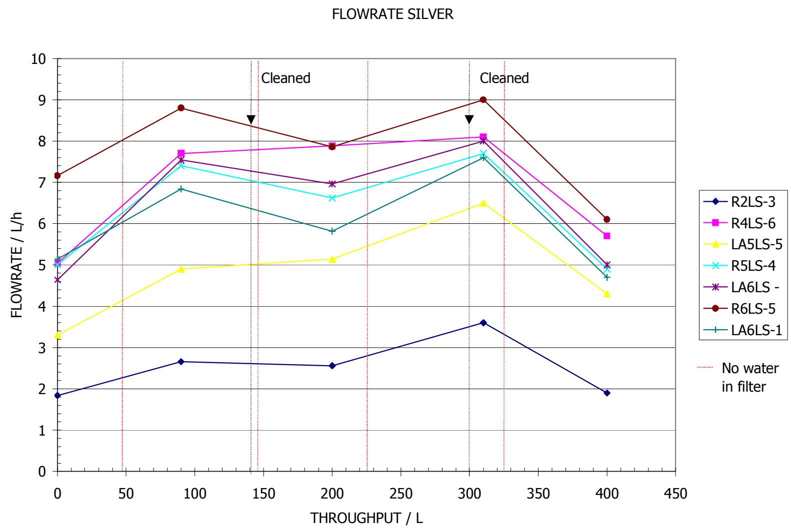


Figure 4.2: Throughput vs. flowrate for filters with silver

For the filters impregnated with silver, there does not seem to be a clear relation between cleaning and flowrate. There does not seem to be a relation between the filter being empty and the flowrate either. For all filters the trend is the same: increase, decrease, increase and decrease again. In Table 4.7, the percentage increase/decrease from the initial flowrate can be seen for the filters with silver. From this table can be seen that after a large initial increase (and same decrease again) the filters did not change much from the initial flowrate. It must be said that there is a possibility that the flowrates will decrease further as result of clogging. There is no faster decline (till so far) of flowrates with an initial higher flowrate.

Table 4.7: Increase/decrease percentages

	R2LS-3	R4LS-6	LA5LS-5	R5LS-4	LA6LS -	R6LS-5	LA6LS-1
in/decrease 0 - 90L / %	44,57	52,78	48,48	48,00	62,50	22,91	33,07
in/decrease 0 - 200L / %	0,39	0,56	0,56	0,32	0,50	0,10	0,13
in/decrease 0 - 310L / %	0,96	0,61	0,97	0,54	0,72	0,26	0,48
in/decrease 0 - 400L / %	0,03	0,13	0,30	-0,02	0,08	-0,15	-0,09

Van Halem (2007) concluded that there was no difference between filters with and without silver. Here the initial trends differ. If the same filters (for example R4L-3 and R4LS-6) will stabilize to the same flowrate cannot yet be said.

4.1.4 E.coli versus throughput

For one month the removal of *E.coli* by the 14 different filters was measured. The Log Reduction Value (LRV), which is defined in [4.1] was calculated for each filter after every 30L throughput.

$$LRV = LOG10\left(\frac{In}{Out}\right) \qquad [4.1]$$

Where,

In = the number of coliforming units per ml that goes *in* the filter (cfu/ml)
Out = the number of coliforming units per ml that flows *out* the filter (cfu/ml)

The LRV corresponds with a percentage of reduction. In Table 4.8 some of these corresponding values are given:

Table 4.8: LRV and reduction

LRV	Reduction / %
0,1	20
0,5	68
1	90
2	99
3	99,9
4	99,99
5	99,999
6	99,9999
7	99,999999

Figure 4.3 shows the LRV versus the throughput of the filters without silver and Figure 4.4 shows this for the filters impregnated with silver. The additional arrow in Figure 4.4 indicates that after 200L throughput, the cfu/ml of the input was increased. This is further discussed below. Figure 4.5 shows both graphs (with and without silver) in one figure.

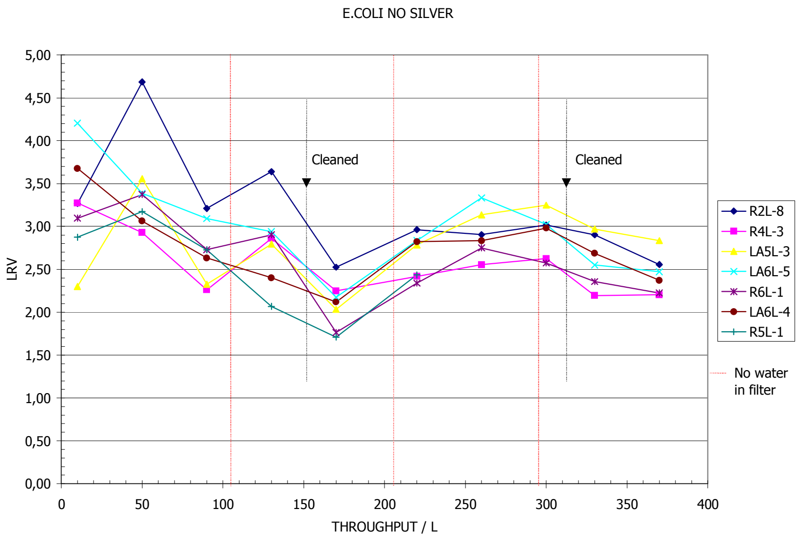


Figure 4.3: Throughput vs. LRV for *E.coli*, filters without silver

The LRV's for the filters without silver is higher for the first 50L but stabilized after 200L throughput. It is interesting that the LRV after the possible biofilm formation slightly higher is. At first glance there is no big difference between the different flowrates and performance. In the first 200L throughput the slowest filter (R2L-8) outer performs the others. After 370L throughput all filters have LRV between 2.2 and 2.83. No large difference in performance can be seen (yet) for filters with increased laterite. LA5L-3 has the highest LRV, but the flowrate is lower than the other filters as well: at the end of this section the flowrate is set out versus the LRV.

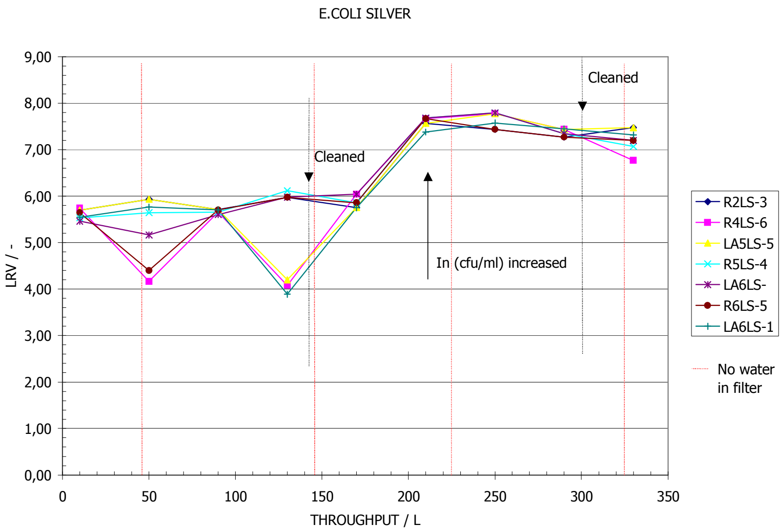


Figure 4.4: Throughput vs. LRV for *E.coli*, filters with silver

The LRV for the filters impregnated with silver is high. The increase in LRV at 210L is due to an increase in the number coliforming units per ml in the influent. The reason for the increase was that all 100 ml samples of the effluent contained 0 cfu/ml. A count of 1 cfu/100 ml must be used, to calculate the LRV, while with no counts the LRV even might be higher. After increasing the influent concentration of *E.coli*, most of the filters *still* did not show any cfu/100ml. This means that the LRV even might be higher than can be seen in Figure 4.4. The raw data can be found in Appendix G.

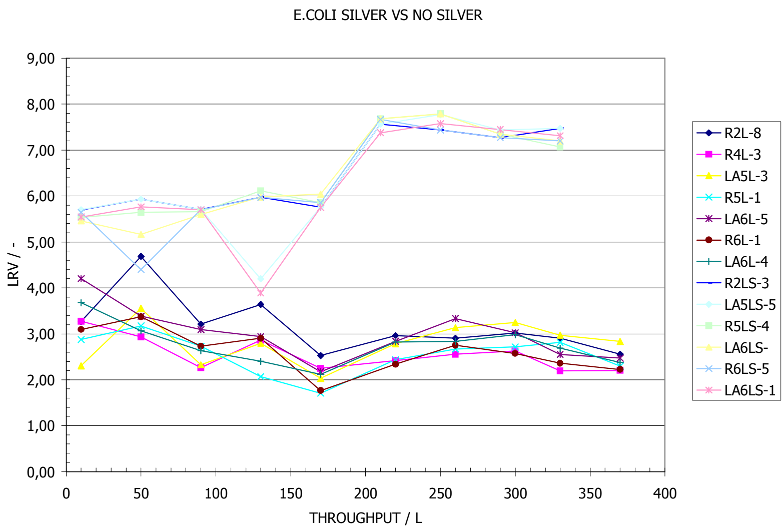


Figure 4.5: Throughput vs. LRV for E.coli for filters with silver

Figure 4.5 shows the important role of silver as a biocide. The filters impregnated with silver all have a much higher LRV then the filters without silver.

Figures 4.6 and 4.7 show the relation of the flowrate versus the LRV for *E.coli*. Separate graphs are made for the filters with and without silver.

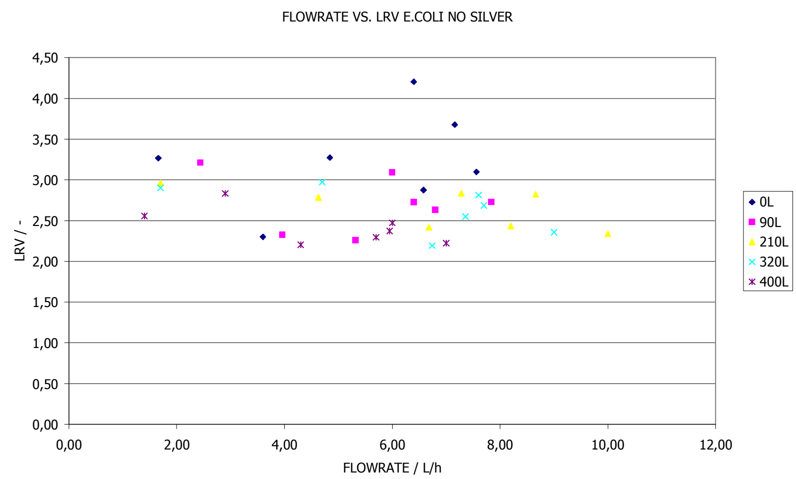


Figure 4.6: Flowrate vs. LRV for *E.coli* for filters without silver

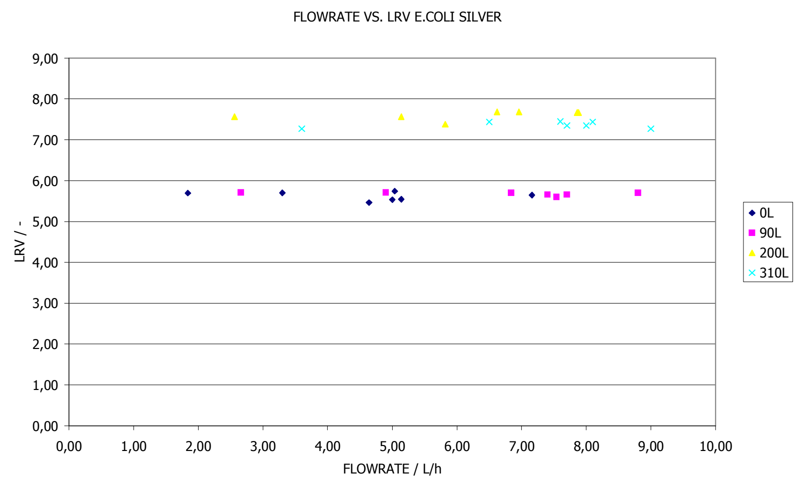


Figure 4.7: Flowrate vs. LRV for *E.coli* for filters with silver

Figure 4.7 and 4.8 show that there is no strong indication for the first 400L throughput that for a higher flowrate the removal efficiency for *E.coli* is lower than for filters with a lower flowrate. For the filters without silver there is a only a slight decreasing trend for the removal versus the flowrate.

Brown (2007) concluded that there was no significant difference between the filters painted with silver or without silver. As can be seen from Figure 4.5, the higher removal of the filter with silver compared to the filters without silver is shown in this research. Brown used filters manufactured by RDI as well, so why are the differences so large? A possible explanation is the source of silver used. The CWF's in this internship were all painted with a solution of silver nitrate. Although Brown writes he used silver nitrate, Sampson (2008) thought these filters might be painted with another source, namely colloidal silver from Germany. It might be interesting to do further research to different sources of silver.

4.1.5 MS2 versus throughput

The removal of viruses of the filters is measured as well. Often there were problems with the virus measurements. Sometimes the virus did not grow at all and sometimes there was excessive growth (contamination). Two different Log Phage Host (LPH) were used. The first 3 weeks *E.coli F-amp* was used as a LPH. The last week *E.coli C3000* was used. All raw data can be found in Appendix G. Because of the problems with the virus measurements, not as much data is generated as wanted. Figure 4.8, 4.9 and 4.10 show the throughput versus the LRV of MS2. Figure 4.11 and 4.12 show the flowrate versus the LRV's.

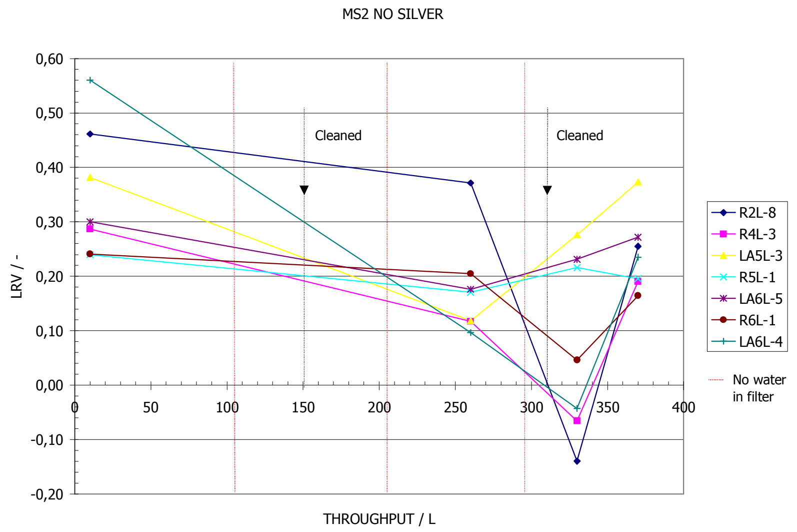


Figure 4.8: Throughput vs. LRV for *MS2* for filters without silver

As can be seen the LRV's are low. Even negative values were obtained. There is no strong indication that the additional laterite had a positive effect on the virus removal, although at 370L throughput, the LRV's of the filters with additional laterite are slightly higher. At 370L for all filters the value is below 0.4. As showed in Table 2.2 higher values for virus removal were obtained in previous researches.

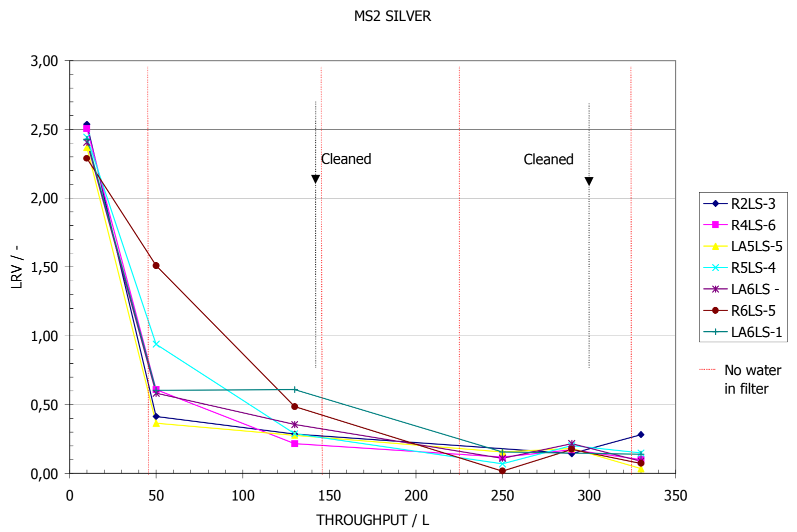


Figure 4.9: Throughput vs. LRV for *MS2* for filters with silver

For the filters impregnated with silver, only the first measurement (at 10L throughput) had a high LRV's: no plaque forming units were detected, therefore the LRV might be even higher. Can we conclude that the working of silver as a biocide is only very strong in the beginning (high concentration)? This is strange, as no silver was detected in the effluent (Section 4.1.5). After 250L throughput, all LRV's for MS2 were lower then 0.3.

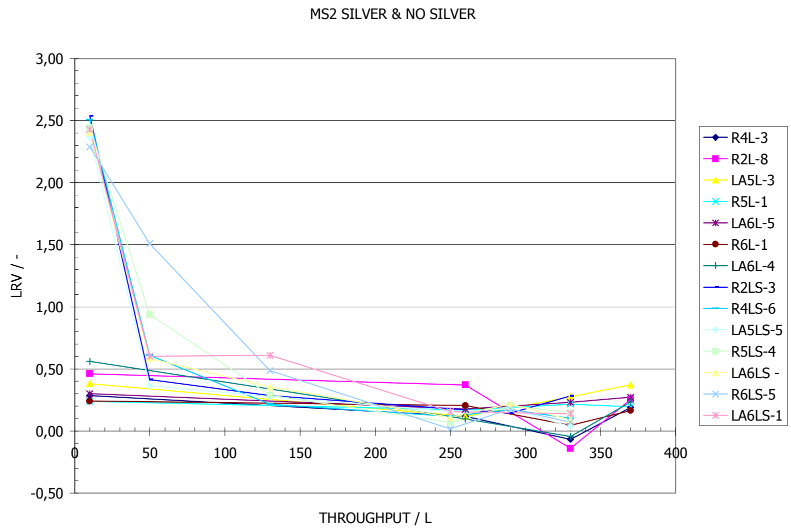


Figure 4.10: Throughput vs. LRV for *MS2* for filters with and without silver

Except for the first measurement (10L throughput), there is no big difference between filters with or without silver. All are below 0.4.

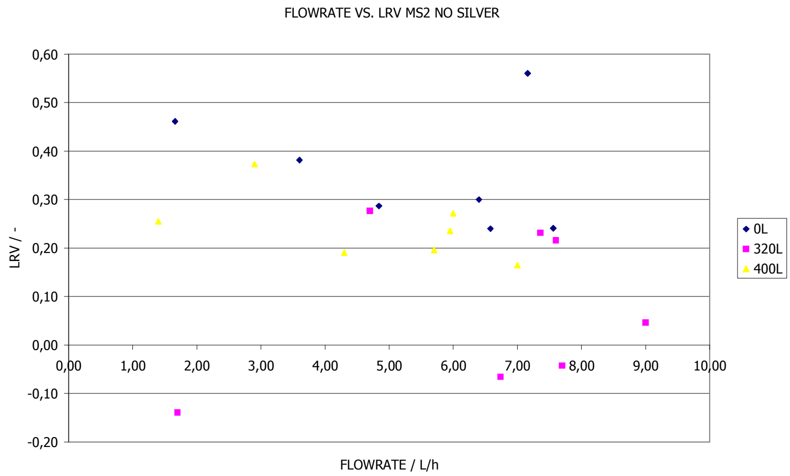


Figure 4.11: Flowrate vs. LRV for *MS2* for filters without silver

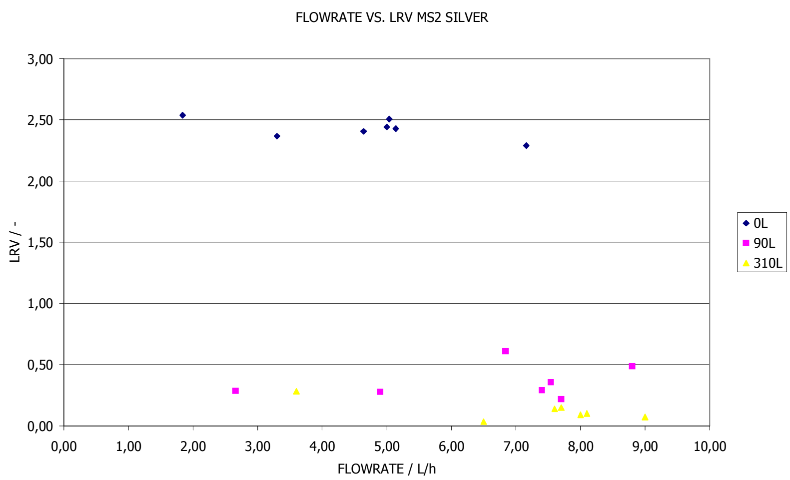


Figure 4.12a: Flowrate vs. LRV for *MS2* for filters without silver

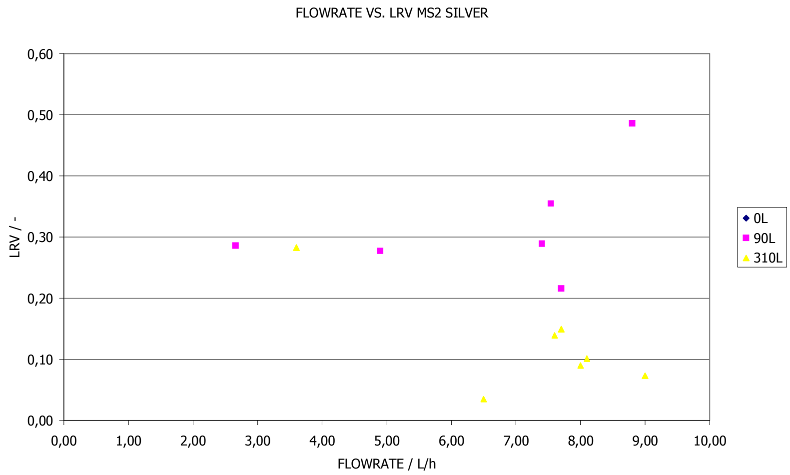


Figure 4.12b: Flowrate vs. LRV for *MS2* for filters without silver (scale changed)

No clear correlation can be seen between flowrate and removal efficiency.

4.1.6 Observations

Interesting, but not surprisingly is that the filters that were not impregnated with silver had biofilm growth on the ceramic filter and in the plastic receptacle. The growth of the biofilm was to the same extent for all filters without silver. The filters were very smelly due to the slimy biofilm. No biofilm, on the ceramic filter nor in the plastic receptacle was detected for the filters impregnated with silver. Again an evidence for the working of silver as a biocide.

Another observation was that the filters with increased laterite were much heavier. This is an disadvantage in the usage of the filter.

4.1.7 Silver measurements

Samples of the filters impregnated with silver were brought from Cambodia to the Netherlands to measure the silver content with an Atomic Absorbance Spectroscope (AAS) at the Technical University of Delft. Expected was that with a higher flowrate, the amount of silver leached out of the filter would be higher. Two samples, R2LS-3 with the lowest flowrate and R6L-5 with the highest initial flowrate were measured to check if there was any silver in the effluent of the filters after 10L throughput. Before starting to use a CWF, 30L is filtered through the filter to make sure people do not drink water with silver levels above WHO guidelines. Both samples contained after 40L (30L + 10L) throughput a lower concentration of silver than 0.02 mg/L which is the detection limit of the AAS (below detection limit). Concluded can be that all 'excessive' silver is leached out in the first 30L and that there is no difference in leaching between filters with different flowrate. It might be that the silver colloids in the samples taken got stuck to the plastic wall of the sample bottles (although samples were shaken well). But that this was the only cause that nothing was detected is very unlikely (Padmos, 2008). No conservation (by HNO_3) of the samples was done in Cambodia. So there is a possibility that the silver was precipitated as silver chloride.

4.2 Homogenous mixing

The dry shrinkage, the humidity, the firing shrinkage, weight reduction, water uptake and porosity were calculated for all clay samples taken. The formulas to determine those values can be found in Chapter 3. Here the results are summarized. The raw data can be found in Appendix G. Percentages of difference (for dry shrinkage etc.) between two samples from the same batch were calculated. In Figures 4.13a and 4.13b box-and-whisker plots can be seen for the calculated differences. Q1 is the first quartile, which cuts of the lowest 25% of the data. Q3 is the third quartile, which cuts of 75% of the data. Q0 is the lowest value of the set and Q4 is the highest value of the data.

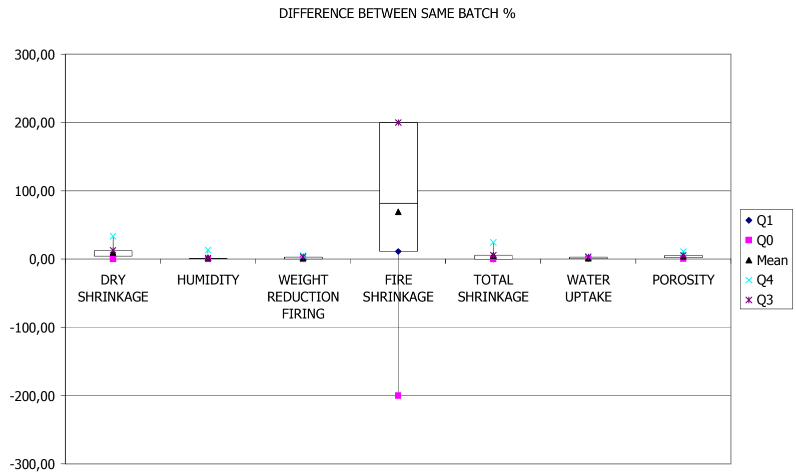


Figure 4.13a: Box-and-whisker plot of difference between one batch

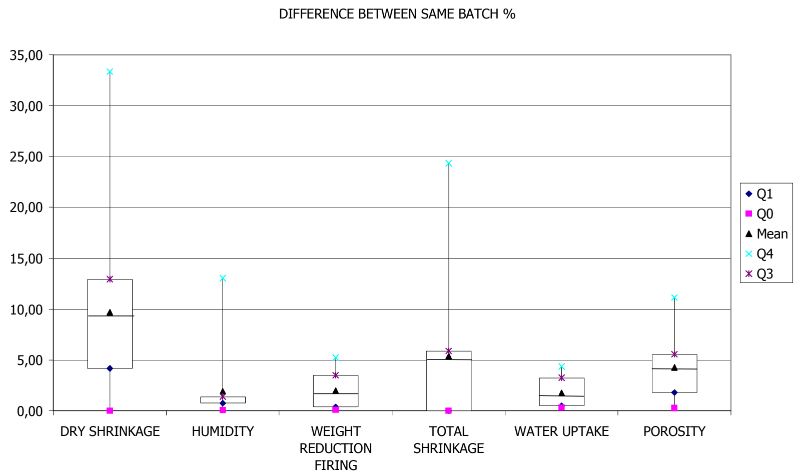


Figure 4.13b: Box-and-whisker plot of difference between one batch without fire shrinkage

As can be seen from Figure 4.13a large difference were found for the fire shrinkage. Some samples had a fire shrinkage of 0%, others of 1.22%. Although this is a small difference, because of the '0%' this ends in high values. In figure 4.13b, the same plot can be seen but without the fire shrinkage. Almost 75% of each characteristics differ less then 5 %, which can be due to inaccuracies in measuring. These low percentages indicates on homogenous mixing. Only for the dry shrinkage the percentages are a little higher, this is due to lower values of raw data. The lower the values the larger the inaccuracy.

In total, four data series are distinguished. A data series consist of clay samples that were placed together in the kiln. The first and second data set had black spots after being fired. This was due to incomplete combustion in the kiln because of lack of oxygen. In Table 4.8 the mean and standard deviation of the the dry shrinkage, the humidity, the firing shrinkage, weight reduction, water uptake and porosity can be seen. 'All data' are dataset 1 to 4 together.

Table 4.8: Mean and standard deviation of datasets

Dataset 1; n = 4	Dry shrinkage / %	Humidity / %	Weight reduction firing / %	Fire shrinkage / %	Total shrinkage / %	Water uptake / %	Porosity / %
Mean	3,18	24,01	24,70	3,58	6,65	34,93	23,73
St. dev.	0,58	0,12	0,28	0,96	0,58	0,53	0,64
Dataset 2; n = 8							
Mean	3,76	23,67	24,30	4,02	7,63	34,92	25,76
St. dev.	0,45	1,42	1,03	0,95	0,89	0,74	0,87
Dataset 3; n = 8							
Mean	4,16	23,22	25,26	-0,09	4,08	41,91	26,65
St. dev.	0,43	0,83	0,66	0,47	0,08	0,57	1,47
Dataset 4; n = 12							
Mean	3,62	23,59	25,11	0,44	4,05	42,85	27,55
St. dev.	0,41	0,74	0,67	0,37	0,14	0,83	0,70
Dataset all; n = 32							
Mean	3,74	23,57	24,89	1,59	5,27	39,64	26,40
St. dev.	0,52	0,93	0,81	1,92	1,69	3,79	1,56

As can be seen from Table 4.8 the firing shrinkage, the total shrinkage and water uptake and porosity differs between the data sets. Mainly between 1-2 and 3-4. This is probably due to the incomplete combustion of dataset 1 and 2. The black spots on the sample (due to incomplete combustion) are coke particles. These particles are still in the pores and therefore reduce the water uptake and total porosity. The standard deviation at every data set is not very large. This indicates on a narrow distribution and therefore no big difference between the mixing of different batches and on homogenous mixing of one batch.

To look more *into* each data set, box and whisker plots are made (Figure 4.13 – Figure 4.19).

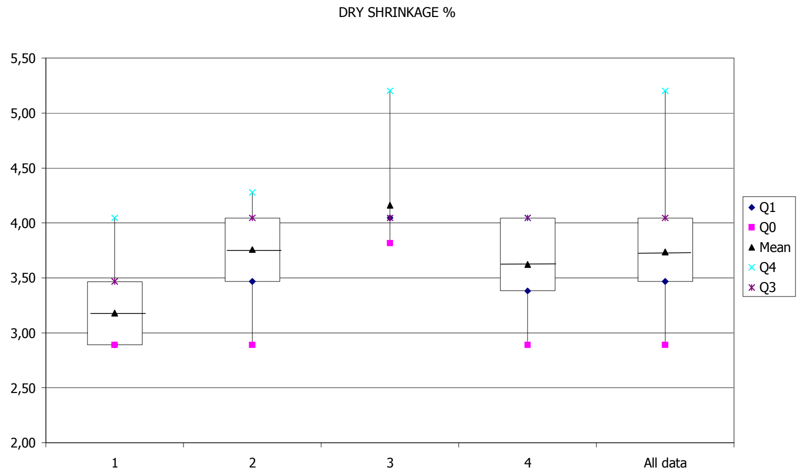


Figure 4.13: Box-and-whisker plot of dry shrinkage

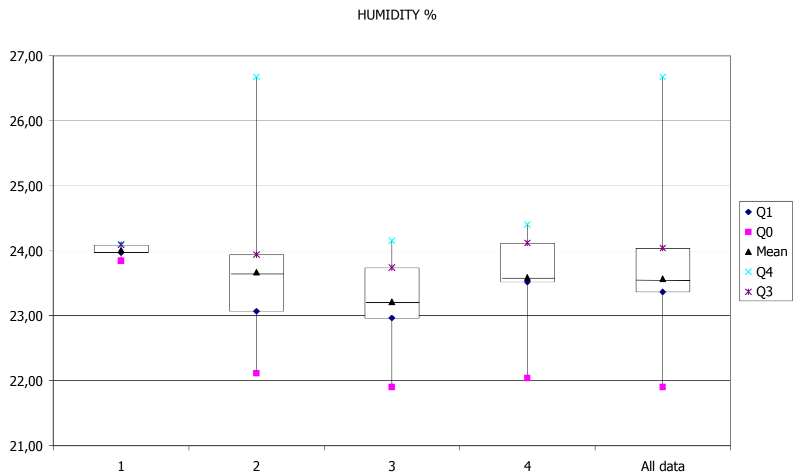


Figure 4.14: Box-and-whisker plot of humidity

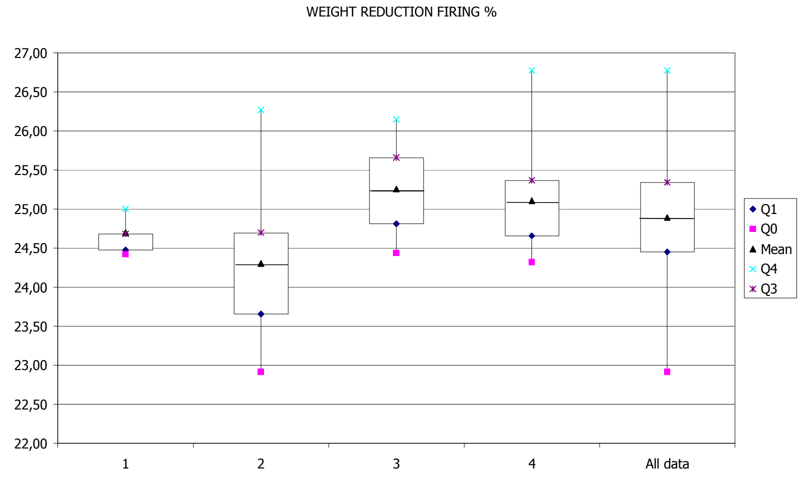


Figure 4.15: Box-and-whisker plot of weight reduction during firing

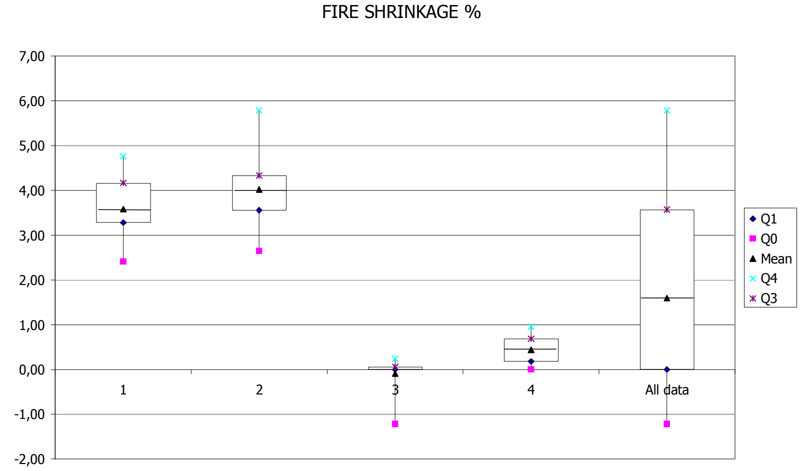


Figure 4.16: Box-and-whisker plot of firing shrinkage

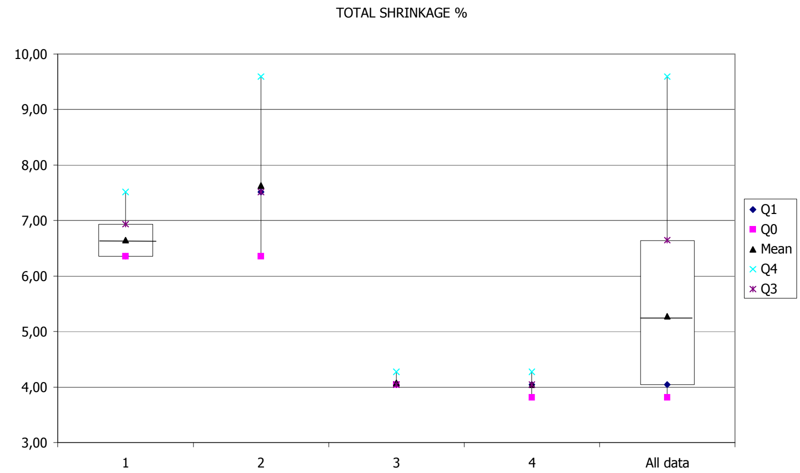


Figure 4.17: Box-and-whisker plot of total shrinkage

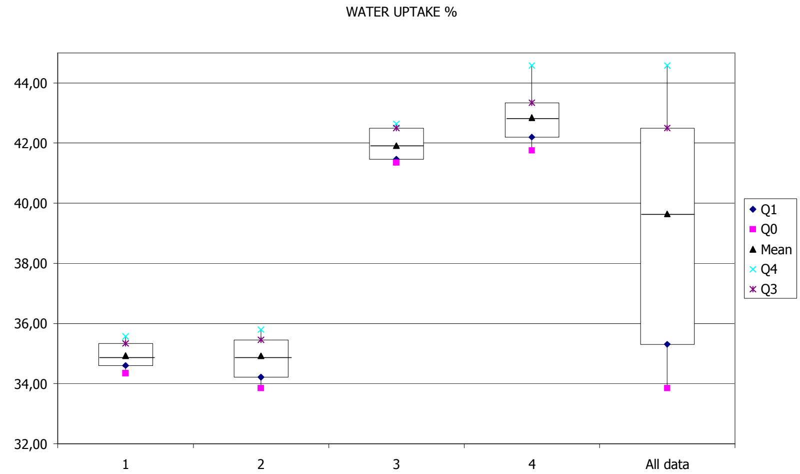


Figure 4.18: Box-and-whisker plot of water uptake

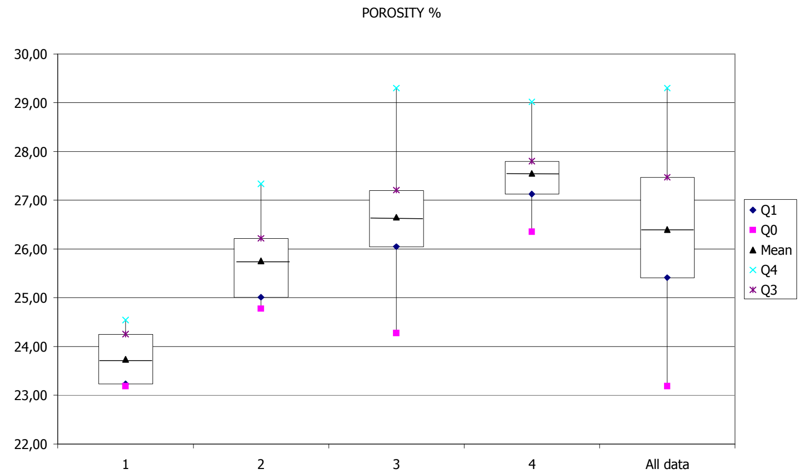


Figure 4.19: Box-and-whisker plot of porosity

From these plots it is found that especially for the firing shrinkage, the total shrinkage, water uptake and porosity there is a difference between datasets 1-2 and 3-4 as already earlier concluded. This is due to incomplete combustion.

Concluded can be that the mixing is homogenous and there are no big differences between different batches. By comparing dataset 3 and 4, it can be concluded that the firing in the kiln was comparable. It is important that the CWF get enough oxygen during firing. Never filters with black spots on the in or outside were seen, so
this is not a problem at RDI.

5. CONCLUSIONS

In this chapter the most important conclusions from the research are repeated.

5.1 Flowrate versus removal of pathogens

5.1.1 Field research

The enquiries of the field research showed that the people are happy with the filters and provide them with enough water for the whole family. This is interesting, because when having a maximum flowrate of 0.68 L/h and 6 family members it is impossible to filter (only for drinking purposes) 3-4 liters for each person. A higher flowrate would be favorable, but only if it works as good as the 'slow' filter or even better. A higher flowrate would also be favorable for purposes as using the CWF at schools.

5.1.2 Flowrate

It can be concluded that by increasing the amount of rice husks or laterite the flowrate of the CWF can be increased. A certain threshold of rice husks and laterite was necessary to really increase the flowrate. Even higher initial flowrates then 9 L/h were obtained. All filters (except for R2L-8) without silver first increased, then decreased. It might be that the flowrates are stabilized after 400L, at 6 to 10% lower then the initial flowrates. It is also possible that the flowrates will decrease further as result of clogging. There is no faster decline till so far of flowrates with an initial higher flowrate.

For the silver impregnated CWF it can be seen that after a large initial increase (and same decrease again) the filters did not change much from the initial flowrate (0.15% decrease to 0.3% increase). It must be said that there is a possibility that the flowrates will decrease further as result of clogging. Also at these filters there was no faster decline till so far of flowrates with an initial higher flowrate, only less increase at the first 90L throughput.

5.1.3 E.coli

Silver plays an important role as a biocide in the removal of *E.coli*. By painting the filters with silver the LRV increases from 2.4 (mean value of filters without silver at 370L) to a value of 7.2 (mean value of filters with silver at 330L). The LRV obtained for the silver impregnated CWF are high compared with literature. Especially because they are probably even higher (no colonies detected in 100 ml output).There is no biofilm growth in or on the ceramic filter nor in the plastic receptacle of the filters with silver. For the filters without silver on the contrary there was growth of biofilm in the filter and in the receptacle. For the filters painted with silver, there is not (yet) a difference in removal of *E.coli* versus the flowrate. Filters with high flowrate have the same LRV as filters with a low flowrate (Figure 4.7). For the filters without silver, there is also no strong indication for a correlation. Though a slight negative slope can be seen of the flowrate versus the LRV (Figure 4.6). Laterite does not seem to play a role in the removal of *E.coli* for the filters with or without silver.

5.1.4 MS2

The LRV's for *MS2* are very low compared to other values in the literature. There is no difference between the filters with or without silver. All have a LRV below 0.4 after one month of testing. For the filters with silver there is no correlation between filters with or without increased laterite. For these silver impregnated filters there is also no relation between removal and flowrate: all filters perform bad regarding virus removal.
For the filters without silver, there is also no strong indication that the additional laterite had an positive effect on the virus removal, although at 370L throughput, the filters with additional laterite are slightly higher. RDI concluded earlier that the addition of laterite had a positive effect on the virus removal, this is not shown here. Filters without silver show a slightly negative slope regarding the flowrate and the removal, but negative values can be seen here as well (Figure 4.11).

5.1.5 Silver

The silver content of effluents samples after 10L throughput of R2LS-3 (flowrate 1.84 L/h) and R6LS-5 (flowrate 7.16 L/h) were measured with AAS.
No silver was detected in these effluent samples. After 40L (30L + 10L) there is no difference in leaching between filters with different flowrate. Concluded can be that all 'excessive' silver is leached out in the first 30L. It was expected that more silver would leach out of the filters with a higher flowrate, but there is no indication for this at all.

5.1 Homogenous mixing

There was no difference between two samples taken from the same batch and there was no difference between different mixed batches. This indicates on homogenous mixing at RDI. Difference in firing shrinkage, the total shrinkage, water uptake and porosity between dataset 1-2 and dataset 3-4 was the result of incomplete combustion of the clay samples. The clay sample of dataset 1 and 2 were placed *in* a CWF, resulting in a lack of oxygen. The clay sample of dataset 3 and 4 were placed *next* to the CWF's in the kiln, all those samples received enough oxygen. The water uptake and porosity of dataset 3 and 4 was very comparable. Concluded is that the firing curves of separate kiln runs are comparable.

ACKNOWLEDGEMENTS

I would like to thank a few people who were involved in my project. First of all I would like to thank Mickey Sampson for all he has done for me. He made my research possible, always had great feedback and helped me communicating with the people of the RDI factory. He also made it possible to continue this research.

Secondly I would like to thank Doris van Halem for communicating with me from the Netherlands and helping me throughout my project. First of all she, together with Mickey Sampson, made this project in Cambodia possible. Thanks, for answering all my question and sending me lots of information.

Further more I would like to thank: Leang Shun and Chan Rith for being my buddies in the lab. They always helped me with my excessive lab work and made me have a good time in the lab. Kunthy and Phearak for continuing this research at RDI in Cambodia. Omon for producing 'my' Ceramic Water Filters with increased flowrate. Samrach for helping with copying, phone calls, printing and viruses on my computer. Joop Padmos for measuring two samples with the AAS at the TU Delft. Lesley Robertson, for responding to my emails and answering my questions about microbiology. Professor van Loosdrecht for being my supervisor. Judy, Hannah, Fran, Erica and Erin for the great support they gave me during my research and for all the fun times we had! Aqua for all and TU Delft to make my internship abroad financially possible.

REFERENCES

Bostic, 2008, Personal communication

Brown, 2007, *Effectiveness of ceramic filtration for drinking water treatment in Cambodia*, Dissertation submitted to the faculty of the University of North Carolina at Chapel Hill in partial fulfillment of the requirements for the degree of Doctor of Philosophy in the Department of Environmental Sciences and Engineering

Brown and Sobsey, 2006, *Independent Appraisal of Ceramic Water Filtration Interventions in Cambodia: Final Report*, University of North Carolina School of Public HealthDepartment of Environmental Sciences and Engineering, Submitted to UNICEF – Cambodia, 5 May 2006

Brown, 2004, *Preliminary phage results on binding to clays/clay additives and ceramic filters*, document for internal review, UNC Department of Environmental Sciences and Engineering

Brown and Sobsey, Powerpoint presentation, *Ceramic filter augmentation for improved reduction of viruses in drinking water*, University of North Carolina – Chapel Hill, Department of Environmental Sciences and Engineering; refers to Ryan et al. 2002, Gerba 1984, Murray & Laband 1979

Butkus, 2004, *The efficacy of silver as a bactericidal agent: advantages, limitations, and considerations for future use*, J. Water Supply Res. Technol. AQUA 52, p.407-415

Latagne, 2001, *Investigation of the Potters for Peace Colloidal Silver Impregnated Ceramic Filter, Report 1: Intrinsic Effectiveness*

Padmos, TUDelft/TNW/DCT/O&O, 2008, Personal communication

Van Halem, 2006*, Ceramic silver impregnated pot filters for household drinking water treatment in developing countries*, Master of Science Thesis in Civil Engineering, Department of Water Management Sanitary Engineering Section

Van Halem, 2007, *Ceramic silver impregnated pot filters for household drinking water treatment in developing countries: material characterization and performance*, Water Science & Technology: Water Supply 2007, Vol 7 No 5-6 pp 9–19

Van Halem, 2007a, *Assesing the sustainibility of the silver-impregnated ceramic pot filter for low-cost household drinking water treatment*, Physics and chemistry of the earth – Sustainable Water Solutions

Hagan, 2008, *RDIC Ceramic Water Filter Handbook*, Resource Development International – Cambodia, Developed in partnership with Engineers Without Borders -Australia

Youwen et al, 2005, *Removal and inactivation of waterborne viruses using zerovalent iron*, Environmental science & technology, VOL. 39, NO. 23, 2005 p. 9263-9269

Russell, 1994, *Antimicrobial Activity and Action of Silver*, Progress in Medicinal Chemistry. Volume 31

RDI, 2008, www.rdic.org, visited website on 27-7-2008

Sampson, 2008, Personal communication

WHO (World Health Organization), 2005, Minimum water quantity needed for domestic use in emergencies

SILVER IMPREGNATED CERAMIC WATER FILTER

Flowrate versus the removal efficiency of pathogens

APPENDIX

CONTENT

APPENDIX A

Research proposal, submitted 18 January 2008

This research internship will consist of two parts. Both are shortly described below.

Part 1: Research to the reliability of the production of the ceramic compounds at RDIC

In this part the reliability of the material of the Ceramic Water Filter is examined. There is a possibility that the mixing is incomplete, resulting in a non-homogeneous mixture. Because of this non-homogeneous mixture the CWF are not completely reproducible. There are differences for example in porosity, resulting in a different throughput of the water and a possible reduced microbiological efficiency. In this first part of the research the consistency of the CWF material is examined. The purpose of 'Part 1' is to check of the mixing is complete.

The procedure will be as followed:

Every day two samples will be taken from a batch after the mixing of the compounds with water. These samples are pressed in a plastic disc with an internal diameter of 8.8 cm and internal height of 1.3 cm. The samples are labeled and measured are the following:

- The weight of the discs (m_{disc})
- The weight of the clay in the discs, together with disc (m_{wet})
- Diameter of the disc (D_{disc})

Secondly, these discs containing the clay are placed outside for two days (temperature is ~ 30C°); the samples are sun dried. In the normal process the CWF is dried for two weeks. Two days is enough for the samples to remove all the excess water which is necessary for moulding the clay into the desired shape.
After drying the following is measured:

- The weight (m_{dry})

Afterwards the plastic discs are removed. Measured is:

- The weight of the clay (as a check) ($m_{dry\_no\ disc}$)
- The diameter of the clay (D_{dry})

The dry-shrinkage of the clay together with the humidity can now be determined.

$$\text{Dry shrinkage} = \frac{D_{disc} \quad D_{dry}}{D_{disc}} \bullet 100\%$$

$$\text{Humidity} = \frac{m_{wet} \quad m_{dry}}{m_{wet}} \bullet 100\%$$

Next the clay samples are placed in a pot at a standard spot in one of the production kilns. Orton cones are placed next to the pot to determine the temperature. Two Orton cones are used by RDI. The first cone has a melting point of 830C°, to indicate that the desired temperature is almost reached. And a second cone, with a melting point of 866 C°. Small Orton cones numbers 014 (melting point 880C°), 016 (melting point 825C°) and 018 (melting point 755C°) are placed next to the clay samples. Ten pieces of clay containing four cones are placed at ten different spots in the kiln (see attached pictures). After the firing of the CWF's, the highest reached temperature in the kiln can be roughly determined. This might be interesting because of problems of insufficient burning of the organic matter, due to insufficient heating or a not optimal firing temperature curve.

After firing the clay samples, the following is measured:

- The weight of the samples m_{fired}
- The diameter D_{fired}

The reduction in weight regarding the dry weight (m_{dry}) can be determined. Secondly the fire shrinkage (regarding the diameter of the dry clay) and the total shrinkage (regarding the diameter of the wet clay) can be calculated.

$$\text{Weight reduction} = \frac{m_{dry} - m_{fired}}{m_{dry}} \bullet 100\%$$

$$\text{Fire shrinkage} = \frac{D_{dry} - D_{fired}}{D_{dry}} \bullet 100\%$$

$$\text{Total shrinkage} = \frac{D_{disc} - D_{fired}}{D_{disc}} \bullet 100\%$$

Finally measurements are done with the fired clay cakes. The clay is held under water for 24h and is weighted (m_{water}). By comparing this weight with m_{fired}, the total take up of water can be determined. Afterwards, the clay is dried again and the thickness and the throughput are measured.

$$\text{Water uptake} = \frac{m_{water} - m_{fired}}{m_{fired}} \bullet 100\%$$

The samples are collected and send to the Netherlands.

Part 2: Increase of the flowrate

The flowrate through the CWF is known to be about 1 - 2 L/h. CWF's are tested before they are impregnated with an $AgNO_3$ solution. If the flowrate is between 1.5 – 3 L/h the CWF is accepted. When the flowrate is too low, below 1 L/h, the filter is rejected mainly because of providing insufficient water. When the flowrate exceeds 3 L/h the filters are destroyed. It is said that with such a high flowrate insufficient filtering takes place and/or the residence time in the filter is too short.

When observing the testing, it is noticed that the flowrate varies between the CWF's. The flowrate varies roughly between 1 and 2 L/h. The CWF's are made according to the same recipe. This difference in flowrate might be because of incomplete mixing and different spots of the filters in the kiln.

A disadvantage of the CWF is the relatively low flowrate. Starting with an initially flowrate of 1 – 2L/h it decreases due to clogging of the filter. Weekly scrubbing the filter rejuvenate the filter only temporarily. Flowrates as low as 0.50L/h are measured which is too low to provide a family of sufficient safe drinking water (Halem, 2007). During this internship a field research will be done to the flowrate. The flowrate will be measured at different households (number yet to be determined). Secondly a survey will determine if people have problems with the low flowrate of the CFW. With the solution of the 20L tank on top of the filter the people might run the CWF overnight as well and obtain enough water.

To my knowledge the flowrate is not tried to vary on purpose before while testing it against the microbiological performance / effectiveness. It might be that when starting with an initial flowrate end in a higher final flowrate. Though, Latagne (2001) tested different CWF with different flowrate in time. The CWF with the highest initial flowrate had the lowest flowrate after a year. This might be due to earlier clogging of the larger pores. Van Halem (2006) did a flowrate testing in time as well for 12 weeks. Here the CWF with the highest initial flowrate had the largest final flowrate (though significantly decreased).

Next to the field research the flowrate of the CWF's is tried to be increase by:

1) Increasing the mass percentages of rice husks.
2) Increasing the mass percentages of laterite.

1. Increase with rice husk
By increasing the amount of rice husk, the total pore volume will increase resulting in an increase of flowrate. Rice husk is the organic material in the CWF, which is burnt out during the firing process and creates pores. Van Halem (2006) says that isolated pores do not contribute to the flowrate. While Sampson (personal communication) thinks it does. He believes that when increasing the mass percentage of rice husk, the number of isolated pores (and thus total pore volume / porosity) will increase. Though it is possible when the rice husk concentration is too high, large interconnected pores will develop. The structure of the CWF is still subject to debate. SEM (Latagne, 2001) shows that besides cracks and spaces pores show to be in the range of 0.6 – 2 micron. Van Halem (2006) measured a characteristic pore length between 16 and 25 micron with mercury intrusion porosimetry, though pore sizes as small as 0,1 micron were measured for CWF produced in Ghana and Nicaragua. An effective mean pore size of 40 micron was measured with bubble-point tests.

2. Increase with laterite
Laterite is added to the CWF because it contains iron oxide. Iron oxide showed to have positive effects on the removal of viruses. Virus inactivation appears to be associated with the strength of electrostatic attraction due to virus/surface charge differential, but may be due to other factors (Brown & Sobsey). Though, in further research it was found there was no difference in the removal of viruses between filters with and without laterite (Brown, 2007), although scrubbing of the filter in the laboratory testing was done weekly. It might be that the concentration of iron oxide in the filter is too low and/or that the actives sites of iron oxide are blocked by a biofilm developing in time. It was found that when increasing the amount of laterite the flowrate of the filter increased. Because a flowrate between 1 – 2 L/h is a rule of thumb it was decided to keep the mass percentages of laterite as low as 5%.
Because the purpose of this part of the research is to increase the flowrate, the mass percentage of laterite is increased. This increase of laterite might have a positive effect on the virus removal as well as on the arsenic leaching out of the clay (Sampson).

Three batches with an increase in rice husk and three batches with an increase in laterite will be prepared. Every batch produces about five filters. Filters may break during firing. Therefore it is assumed that for every batch four CWF are produced. The aimed flowrates are 4, 5 and 6 L/h.

After drying and firing these CWF's, they will be tested. Only two of every batch will be impregnated with the silver solution. The challenge water (surface or rain; yet to be determined) will be spiked with E.coli and MS2. The influence of the percentage rice husk / laterite on the initial flowrate can be determined. The flowrate will be measured against the time / total throughput. Secondly the influence of the flowrate on the microbiological efficiency is determined. This will be done with and without silver. Table 1 gives an overview of the different CWF produced:

Table A.1: Different CWF to be produced

Filter	Compound increased	Aimed Flowrate (L/h)	Silver (yes/no)
CWF_2L	Standard	2	no
CWF_2LS	Standard	2	yes
CWF_R4L	Rice husks	4	no
CWF_R4LS	Rice husks	4	yes
CWF_R5L	Rice husks	5	no
CWF_R5LS	Rice husks	5	yes
CWF_R6L	Rice husks	6	no
CWF_R6LS	Rice husks	6	yes
CWF_La4L	Laterite	4	no
CWF_La4LS	Laterite	4	yes
CWF_La5L	Laterite	5	no
CWF_La5LS	Laterite	5	yes
CWF_La6L	Laterite	6	no
CWF_La6LS	Laterite	6	yes

All CWF are measured in duplo; there are two CWF_2L, two CFW_2LS etc. The composition of the mixtures is known by the factory operator and will be reported in the final report.

References:

Brown and Sobsey, Powerpoint presentation, *Ceramic filter augmentation for improved reduction of viruses in drinking water*, University of North Carolina – Chapel Hill, Department of Environmental Sciences and Engineering; refers to Ryan et al. 2002, Gerba 1984, Murray & Laband 1979

Brown, 2007, *Effectiveness of ceramic filtration for drinking water treatment in Cambodia*, Dissertation submitted to the faculty of the University of North Carolina at Chapel Hill in partial fulfillment of the requirements for the degree of Doctor of Philosophy in the Department of Environmental Sciences and Engineering

Latagne, 2001, *Investigation of the Potters for Peace Colloidal Silver Impregnated Ceramic Filter, Report 1: Intrinsic Effectiveness*

Sampson, personal communication

Van Halem, 2006*, Ceramic silver impregnated pot filters for household drinking water treatment in developing countries*, Master of Science Thesis in Civil Engineering, Department of Water Management Sanitary Engineering Section

van Halem, 2007, Ceramic silver impregnated pot filters for household drinking water treatment in developing countries: material characterization and performance, Water Science & Technology: Water Supply 2007, Vol 7 No 5-6 pp 9–19

APPENDIX B

B.1 Results Raman spectroscopy

Raman analysis was performed on dried solutions, Figure B.1 shows the plot.

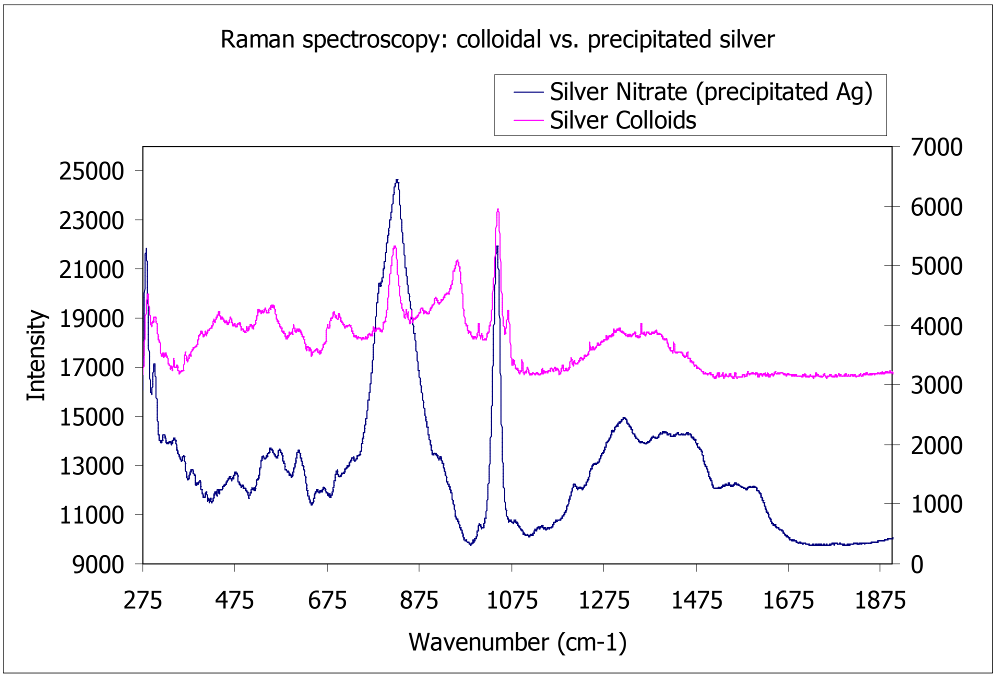


Figure B.1: Raman spectroscopy colloidal vs. silver nitrate

Silver clearly precipitated from the silver nitrate solution upon drying. Both signals are nearly identical. Peaks at ~825 wn are broadened for the precipitated (from silver nitrate) silver, likely indicating a larger particle size than the colloids.

B.2 Dynamic light scattering of colloidal solution

Dynamic light scattering determined the particle size of a colloidal silver solution. The following results were obtained assuming that it are spheres. Those numbers are in the range of 10^{-6} to 10^{-9} as said in Chapter 2.

Table B.1: Dynamic light scattering of colloidal solution

Diameter (nm)	% of particles
5000	5
1860	14
862	81

Reference

Benjamin Kocar
Email: bdkocar@gmail.com
Doctoral Student, Soil and Environmental Biogeochemistry
Building 320, Room 118
Stanford, CA 94305
650-723-7220

APPENDIX C

C.1 Enquiry field research

Village: Family name: Measured flowrate:

Number of people: Source water:

Questions

1. How often do you use water from your filter?

- ☐ Daily
- ☐ Sometimes
- ☐ Never

- If *not* daily; ask why?

……………………………………………..

2. How often (*a day*) do you refill the filter?

- ☐ 1
- ☐ 2
- ☐ 3
- ☐ Other: ….

3. When did you start using the filter / How old is the filter?

- ☐ About 4 months ago
- ☐ 1 year ago
- ☐ > 1 year; about … years

4. Do you find the filter easy / ok / difficult to use?

- ☐ Easy
- ☐ Ok
- ☐ Difficult

5. Do you have any problems with your filter?

- If no, go to 6
- If yes, what kind of problems?

Do not say these examples stated below

- ☐ Flowrate
- ☐ Taste
- ☐ Still get sick / no reduce in diarrhea
- ☐ Cracks in filter / breakage
- ☐ …..
- ☐ ……

6. Are there any advantages of the CWF in comparison with other drinking water options (for example: boiling water, buying water, sandfilter, no cleaning) that you know?

- If no, go to 7
- If yes, can you name the advantages?

  Do not say these examples stated below

  - ☐ Saves time (for example compared to boiling)
  - ☐ Money
  - ☐ Easy
  - ☐ …..
  - ☐ ……

7. Are there any disadvantages of the CWF in comparison with other drinking water options (for example: boiling water, buying water, sandfilter, no cleaning) that you know?

- If no, go to 8
- If yes, can you name the disadvantages?

  Do not say these examples stated below

  - ☐ Slow flowrate
  - ☐ The cleaning
  - ☐ Taste
  - ☐ …..
  - ☐ ……

8. Do you clean the CWF?

  - ☐ Yes
  - ☐ No (*go to last bullet of 8*)

- If yes, how often?
  - ☐ 1 time a month
  - ☐ 2 times a month
  - ☐ 3 times a month
  - ☐ 4 times a month (every week)
  - ☐ Other: …
- How do you clean the filter?
  - ☐ Clean water (from filter) + cloth
  - ☐ Clean water (from filter) + brush
  - ☐ Clean water (from filter) + cloth + soap
  - ☐ Clean water (from filter) + brush + soap
  - ☐ Water + cloth
  - ☐ Water + brush
  - ☐ Water (from filter) + cloth + soap
  - ☐ Water + brush + soap

- ☐ Other: ……

- Do you find it easy or difficult?
  - ☐ Easy
  - ☐ Difficult
- Did you get instruction how to clean?
  - ☐ Yes
  - ☐ No

9. Do you recommend the filter to your family / neighbours / friends?
   - ☐ Yes
   - ☐ No
10. After cleaning do you notice any changes in flowrate of the CWF?

    Do not say these examples stated below
    - ☐ Higher flowrate
    - ☐ Lower flowrate
    - ☐ Better taste
    - ☐ Worse taste
    - ☐ …..
    - ☐ …..
11. If something could be improved of the CWF what would you choose? (Multiple answers possible)

    Do not say these examples stated below
    - ☐ Higher flowrate
    - ☐ No cleaning
    - ☐ Bigger / higher volume
    - ☐ …..
    - ☐ …..
12. Is it enough drinking water for the whole family?
    - ☐ Yes
    - ☐ No
13. Do you use the water for drinking only, or for cooking as well?
    - ☐ Only drinking, because not enough water
    - ☐ Drinking and cooking
    - ☐ Only drinking, other reason ………..
14. Better health (less diarrhea) since using CWF?
    - ☐ Yes
    - ☐ No

C.2 Results field research

1. How often do you use water from your filter?

	#	%
Daily	10	100
Sometimes	0	0
Never	0	0

2. How often (*a day*) do you refill the filter?

	#	%
1	2 (**9, 10**)	20
2	7	70
3	1 (**1**)	10
Other	-	-

4. You find the filter easy / ok / difficult to use?

	#	%
Easy	1	10
Ok	9	90
Difficult	0	0

5. Do you have any problems with your filter?

	#	%
No	9	90
Yes	1(**9, broken tap**)	10

6. Are there any advantages of the CWF in comparison with other drinking water options (for example: boiling water, buying water, sandfilter, no cleaning) that you know?

	#	%
Good health / no diarhea	7	70
Money	8	80
Saves time	6	60
Clean water	2	20

7. Are there any disadvantages of the CWF in comparison with other drinking water options (for example: boiling water, buying water, sandfilter, no cleaning) that you know?

	#	%
No	10	100
Yes	0	0

8. Do you clean the CWF?

	#	%
No	1 (**4**)	10
Yes	9	90

8a. How often?

	#	%
2 times a week	1(**10**)	11,11
1 time a month	1(**9**)	11,11
2 times a month	7	77,78

8b. How do you clean?

FILTER	#	%
Clean water + cloth	1 (**1**)	11,11
Clean water + brush	1 (**5**)	11,11
Clean water + cloth + soap		
Clean water + brush + soap		
Water + cloth	4 (**2, 6, 9, 10**)	44,44
Water + brush	2 (**3, 7**)	22,22
Water + cloth + soap		
Water + brush + soap		
Other: Water	1 (**8**)	11,11

RECEPTACLE	#	%
Clean water + cloth		
Clean water + brush		
Clean water + cloth + soap		
Clean water + brush + soap	2 (**1, 3**)	22,22
Water + cloth	1 (**10**)	11,11
Water + brush	1 (**5**)	11,11
Water + cloth + soap		
Water + brush + soap	5 (**2, 6, 7, 8, 9**)	55,56

8c. Do you find it easy or difficult

	#	%
Easy	9	100
Difficult	0	0

8d. Did you get instruction how to clean?

	#	%
Yes	10	100
No	0	0

9. Do you recommend the filter to your family / neighbours / friends?

	#	%
Yes	10	100
No	0	0

10. After cleaning do you notice any changes

	#	%
Higher flowrate	3 (**7,9,10**)	33,33
Same flowrate	6 (**1,2,3,5,6,8**)	66,67
Better taste	4 (**1,3,6,8**)	44,44
Same taste	3 (**2,9,10**)	33,33
Cleaner water	6 (**1,2,3,5,6,10**)	66,67
Filter looks better	3 (**1,6,8**)	33,33

11. If something could be improved of the CWF what would you choose?

	#	%
Clean water	4	40
Validy of CWF	4	40
no idea	1	10
Nothing	1	10

12. Is it enough for the whole family?

	#	%
Yes	10	100
No	0	0

13. Do you use the water for drinking only, or for cooking as well?

	#	%
Only drinking, because not enough	2 (**1,2**)	20
Drinking and cooking	2 (**4, 10**)	20
Only drinking, other reason: habit	6	60

14. Better health (less diarrhea) since using CWF?

	#	%
Yes	10	100
No	0	0

APPENDIX D

D.1 Results of increase flowrate: attempt 1

Recipes of first attempt to increase flowrate can be found in Table D.1 and Table D.2.

Table D.1: Recipes of attempt 1 with increased rice husk

Raw materials	R2L Mass / kg	R4L Mass / kg	R5L Mass / kg	R6L Mass / kg
Bricks	30	30	30	30
Laterite	2	2	2	2
Rice husk	*8,8*	*8,95*	*9,1*	*10,15*
Water	12,5	12,50	12,5	12,5
Total	53,3	53,45	53,6	54,65

Table D.2: Recipes of attempt 1 with increased laterite

Raw materials	R2L Mass / kg	LA4L Mass / kg	LA5L Mass / kg	LA6L Mass / kg
Bricks	30	30	30	30
Laterite	*2*	*2,3*	*2,6*	*3,2*
Rice husk	8,8	8,8	8,8	8,8
Water	12,5	12,5	12,5	12,5
Total	53,3	53,60	53,9	54,5

The flowrate of these filters can be found in Table D.4 to D.9.

Table D.3: Flowrate attempt 1, R2L

RICE	Aimed flowrate	Number	Measured flowrate
R	2	1	2,00
R	2	2	2,00
R	2	3	2,25
R	2	4	2,00
R	2	5	2,00
R	2	6	2,80
MEAN FLOWRATE			**2,18**

Table D.4: Flowrate attempt 1, R4L

RICE	Aimed flowrate	Number	Measured flowrate
R	4	1	1,50
R	4	2	1,90
R	4	3	2,00
R	4	4	1,00
R	4	5	-
R	4	6	1,50
MEAN FLOWRATE			**1,58**

Table D.5: Flowrate attempt 1, R5L

RICE	Aimed flowrate	Number	Measured flowrate
R	5	1	2,25
R	5	2	2,50
R	5	3	2,60
R	5	4	2,25
R	5	5	2,50
R	5	6	3,00
MEAN FLOWRATE			**2,52**

Table D.6: Flowrate attempt 1, R6L

RICE	Aimed flowrate	Number	Measured flowrate
R	6	1	1,50
R	6	2	1,50
R	6	3	-
R	6	4	2,40
R	6	5	1,70
R	6	6	1,80
MEAN FLOWRATE			**1,78**

Table D.7: Flowrate attempt 1, LA4L

LATERITE	Aimed flowrate	Number	Measured flowrate
LA	4	1	1,25
LA	4	2	-
LA	4	3	1,50
LA	4	4	-
LA	4	5	1,20
LA	4	6	1,00
MEAN FLOWRATE			**1,24**

Table D.8: Flowrate attempt 1, LA5L

LATERITE	Aimed flowrate	Number	Measured flowrate
LA	5	1	2,00
LA	5	2	1,75
LA	5	3	1,50
LA	5	4	1,50
LA	5	5	1,25
LA	5	6	2,00
MEAN FLOWRATE			**1,67**

Table D.9: Flowrate attempt 1, LA6L

LATERITE	Aimed flowrate	Number	Measured flowrate
LA	6	1	-
LA	6	2	1,50
LA	6	3	1,50
LA	6	4	1,40
LA	6	5	2,00
LA	6	6	1,50
MEAN FLOWRATE			**1,58**

D.2 Results of increase flowrate: attempt 2

In Table D.10 to D.15, the initial flowrate of the filters of attempt 2 can be found. The selected filters for testing are *Italic*. *Nosilver* or *silver* behind the selected filter in the Tables, indicates if that particular selected filters was painted or not.

Table D.10: Flowrate attempt 2, R4L

RICE	Aimed flowrate	Number	Meas. flowrate 30 min.	Cal. after 1 h	Measured flowrate 1h	
R	4	1	2,00	4,00	3,25	
R	4	2	2,00	4,00	3	
R	*4*	*3*	*2,50*	*5,00*	***3,75***	*nosilver*
R	*4*	*6*	*2,50*	*5,00*	***4***	*silver*
R	4	5	2,00	4,00	3,25	
MEAN FLOWRATE			2,20	4,40	3,45	

Table D.11: Flowrate attempt 2, R5L

RICE	Aimed flowrate	Number	Meas. flowrate 30 min.	Cal. after 1 h	Measured flowrate 1h	
R	*5*	*1*	*2,75*	*5,50*	***4,5***	*nosilver*
R	5	2	3,00	6,00	4,75	
R	5	3	2,50	5,00	4	
R	*5*	*4*	*2,80*	*5,60*	***4,5***	*silver*
R	5	5	2,00	4,00	3	
R	5	6	4,00	8,00	6,25	
MEAN FLOWRATE			2,84	**5,68**	4,5	

Table D.12: Flowrate attempt 2, R6L

RICE	Aimed flowrate	Number	Meas. flowrate 30 min.	Cal. after 1 h	Measured flowrate 1h	
R	*6*	*1*	*3,50*	*7,00*	***5,5***	*nosilver*
R	6	2	4,75	9,50	7	
R	6	3	3,00	6,00	5	
R	6	4	4,00	8,00	6	
R	*6*	*5*	*3,50*	*7,00*	***5,5***	*silver*
R	6	6	5,00	10,00	7	
MEAN FLOWRATE			**4,75**	**7,92**	6	

Table D.13: Flowrate attempt 2, LA4L

LATERITE	Aimed flowrate	Number	Meas. flowrate 30 min.	Cal. after 1 h	Measured flowrate 1h
LA	4	1	1,50	3,00	2,5
LA	4	2	1,00	2,00	1,5
LA	4	3	2,00	4,00	3
LA	4	5	1,40	2,80	2
LA	4	6	1,00	2,00	1,5
MEAN FLOWRATE			**1,73**	2,76	2,1

Table D.14: Flowrate attempt 2, LA5L

LATERITE	Aimed flowrate	Number	Meas. flowrate 30 min.	Cal. after 1 h	Measured flowrate 1h	
LA	5	1	1,50	3,00	2	
LA	5	2	1,50	3,00	2,5	
LA	*5*	*3*	*2,25*	*4,50*	***3,4***	*nosilver*
LA	5	4	1,50	3,00	2	
LA	*5*	*5*	*2,00*	*4,00*	***3,25***	*silver*
LA	5	7	2,00	4,00	3	
LA	6	6	1,75	3,50	2,5	
MEAN FLOWRATE			**1,79**	**3,57**	2,66	

Table D.15: Flowrate attempt 2, LA6L

LATERITE	Aimed flowrate	Number	Meas. flowrate 30 min.	Cal. after 1 h	Measured flowrate 1h	
LA	*6*	*1*	*3,40*	*6,80*	***5***	*silver*
LA	6	2	3,00	6,00	4,25	
LA	6	3	3,00	6,00	4,25	
LA	*6*	*4*	*3,50*	*7,00*	***5***	*nosilver*
LA	*6*	*5*	*3,00*	*6,00*	***4,5***	*nosilver*
LA	6	6	2,00	4,00	3,5	
LA	*6*	-	*3,00*	*6,00*	***4,5***	*silver*
MEAN FLOWRATE			**2,99**	**5,97**	4,43	

APPENDIX E

Overview experiment

Red = Measure flowrate and take silver samples (only for filters with silver)
Bold = Spike and take samples
Green = Clean filter and receptacle

week1		***R2L***	***R4L***	***R5L***	***R6L***	***LA5L***	***LA6L-4***	***LA6L-5***	***R2L-S***	***R4L-S***	***R5L-S***	***R6L-S***	***LA5L-S***	***LA6LS-1***	***LA6LS-***
Monday	Morning	**10L**	**10L**	**10L**	**10L**	**10L**	**10L**	**10L**	-	-	-	-	-	-	-
	Evening	20L	20L	20L	20L	20L	20L	20L	-	-	-	-	-	-	-
Tuesday	Morning	30L	30L	30L	30L	30L	30L	30L	-	-	-	-	-	-	-
	Evening	40L	40L	40L	40L	40L	40L	40L	-	-	-	-	-	-	-
Wed	Morning	**50L**	**50L**	**50L**	**50L**	**50L**	**50L**	**50L**	-	-	-	-	-	-	-
	Evening	60L	60L	60L	60L	60L	60L	60L	-	-	-	-	-	-	-
Thursday	Morning	70L	70L	70L	70L	70L	70L	70L	**10L**	**10L**	**10L**	**10L**	**10L**	**10L**	**10L**
	Evening	80L	80L	80L	80L	80L	80L	80L	20L	20L	20L	20L	20L	20L	20L
Friday	Morning	**90L**	**90L**	**90L**	**90L**	**90L**	**90L**	**90L**	30L	30L	30L	30L	30L	30L	30L
	Evening	100L	100L	100L	100L	100L	100L	100L	40L	40L	40L	40L	40L	40L	40L

week2		***R2L***	***R4L***	***R5L***	***R6L***	***LA5L***	***LA6L-4***	***LA6L-5***	***R2L-S***	***R4L-S***	***R5L-S***	***R6L-S***	***LA5L-S***	***LA6LS-1***	***LA6LS-***
Monday	Morning	110L	110L	110L	110L	110L	110L	110L	**50L**	**50L**	**50L**	**50L**	**50L**	**50L**	**50L**
	Evening	120L	120L	120L	120L	120L	120L	120L	60L	60L	60L	60L	60L	60L	60L
Tuesday	Morning	**130L**	**130L**	**130L**	**130L**	**130L**	**130L**	**130L**	70L	70L	70L	70L	70L	70L	70L
	Evening	140L	140L	140L	140L	140L	140L	140L	80L	80L	80L	80L	80L	80L	80L
Wed	Morning	150L	150L	150L	150L	150L	150L	150L	**90L**	**90L**	**90L**	**90L**	**90L**	**90L**	**90L**
	Evening	160L	160L	160L	160L	160L	160L	160L	100L	100L	100L	100L	100L	100L	100L
Thursday	Morning	**170L**	**170L**	**170L**	**170L**	**170L**	**170L**	**170L**	110L	110L	110L	110L	110L	110L	110L
	Evening	180L	180L	180L	180L	180L	180L	180L	120L	120L	120L	120L	120L	120L	120L
Friday	Morning	190L	190L	190L	190L	190L	190L	190L	**130L**	**130L**	**130L**	**130L**	**130L**	**130L**	**130L**
	Evening	200L	200L	200L	200L	200L	200L	200L	140L	140L	140L	140L	140L	140L	140L

week3		***R2L***	***R4L***	***R5L***	***R6L***	***LA5L***	***LA6L-4***	***LA6L-5***	***R2L-S***	***R4L-S***	***R5L-S***	***R6L-S***	***LA5L-S***	***LA6LS-1***	***LA6LS-***
Monday	Morning	210L	210L	210L	210L	210L	210L	210L							
	Evening														
Tuesday	Morning	**220L**	**220L**	**220L**	**220L**	**220L**	**220L**	**220L**	150L	150L	150L	150L	150L	150L	150L
	Evening	230L	230L	230L	230L	230L	230L	230L	160L	160L	160L	160L	160L	160L	160L
Wed	Morning	240L	240L	240L	240L	240L	240L	240L	**170L**	**170L**	**170L**	**170L**	**170L**	**170L**	**170L**
	Evening	250L	250L	250L	250L	250L	250L	250L	180L	180L	180L	180L	180L	180L	180L
Thursday	Morning	**260L**	**260L**	**260L**	**260L**	**260L**	**260L**	**260L**	190L	190L	190L	190L	190L	190L	190L
	Evening	270L	270L	270L	270L	270L	270L	270L	200L	200L	200L	200L	200L	200L	200L
Friday	Morning	280L	280L	280L	280L	280L	280L	280L	**210L**	**210L**	**210L**	**210L**	**210L**	**210L**	**210L**
	Evening	290L	290L	290L	290L	290L	290L	290L	220L	220L	220L	220L	220L	220L	220L

week4		***R2L***	***R4L***	***R5L***	***R6L***	***LA5L***	***LA6L-4***	***LA6L-5***	***R2L-S***	***R4L-S***	***R5L-S***	***R6L-S***	***LA5L-S***	***LA6LS-1***	***LA6LS-***
Monday	Morning	**300L**	**300L**	**300L**	**300L**	**300L**	**300L**	**300L**	230L	230L	230L	230L	230L	230L	230L
	Evening	310L	310L	310L	310L	310L	310L	310L	240L	240L	240L	240L	240L	240L	240L
Tuesday	Morning	320L	320L	320L	320L	320L	320L	320L	**250L**	**250L**	**250L**	**250L**	**250L**	**250L**	**250L**
	Evening								260L	260L	260L	260L	260L	260L	260L
Wed	Morning	**330L**	**330L**	**330L**	**330L**	**330L**	**330L**	**330L**	270L	270L	270L	270L	270L	270L	270L
	Evening	340L	340L	340L	340L	340L	340L	340L	280L:	280L:	280L:	280L:	280L:	280L:	280L:
Thursday	Morning	350L	350L	350L	350L	350L	350L	350L	**290L**	**290L**	**290L**	**290L**	**290L**	**290L**	**290L**
	Evening	360L	360L	360L	360L	360L	360L	360L	300L	300L	300L	300L	300L	300L	300L
Friday	Morning	**370L**	**370L**	**370L**	**370L**	**370L**	**370L**	**370L**	310L	310L	310L	310L	310L	310L	310L
	Evening								320L	320L	320L	320L	320L	320L	320L

week5		***R2L***	***R4L***	***R5L***	***R6L***	***LA5L***	***LA6L-4***	***LA6L-5***	***R2L-S***	***R4L-S***	***R5L-S***	***R6L-S***	***LA5L-S***	***LA6LS-1***	***LA6LS-***
Monday	Morning	380L	380L	380L	380L	380L	380L	380L	**330L**	**330L**	**330L**	**330L**	**330L**	**330L**	**330L**
	Evening	390L	390L	390L	390L	390L	390L	390L	340L	340L	340L	340L	340L	340L	340L
Tuesday	Morning	400L	400L	400L	400L	400L	400L	400L	350L	350L	350L	350L	350L	350L	350L
	Evening								360L	360L	360L	360L	360L	360L	360L
Wed	Morning														
	Evening														
Thursday	Morning	410L	410L	410L	410L	410L	410L	410L	370L	370L	370L	370L	370L	370L	370L
	Evening														
Friday	Morning	cleaned	cleaned	cleaned	cleaned	cleaned	cleaned	cleaned	380L	380L	380L	380L	380L	380L	380L
	Evening	420L	420L	420L	420L	420L	420L	420L	390L	390L	390L	390L	390L	390L	390L

Sunday								400L	400L	400L	400L	400L	400L	400L

APPENDIX F

F.0: Research follow up

Research part I is continued by staff of RDI. A document for this follow up experiment was made together with a schedule and results form. These documents can be found in this Appendix of this document, named Appendix follow-up.

FOLLOW – UP FILTERS WITH DIFFERENT FLOWRATES

In total 14 ceramic water filters are tested. 7 are painted *with* silver, and 7 filters are *not* painted with silver. The 7 filters painted *with* silver are placed on the bottom of the rack. The 7 filters *without* filters are placed on the top. Two filters (1 with and 1 without silver) are placed on the floor, because lack of space in the racks.

Figure F.1 represents a schematic drawing of the set-up.

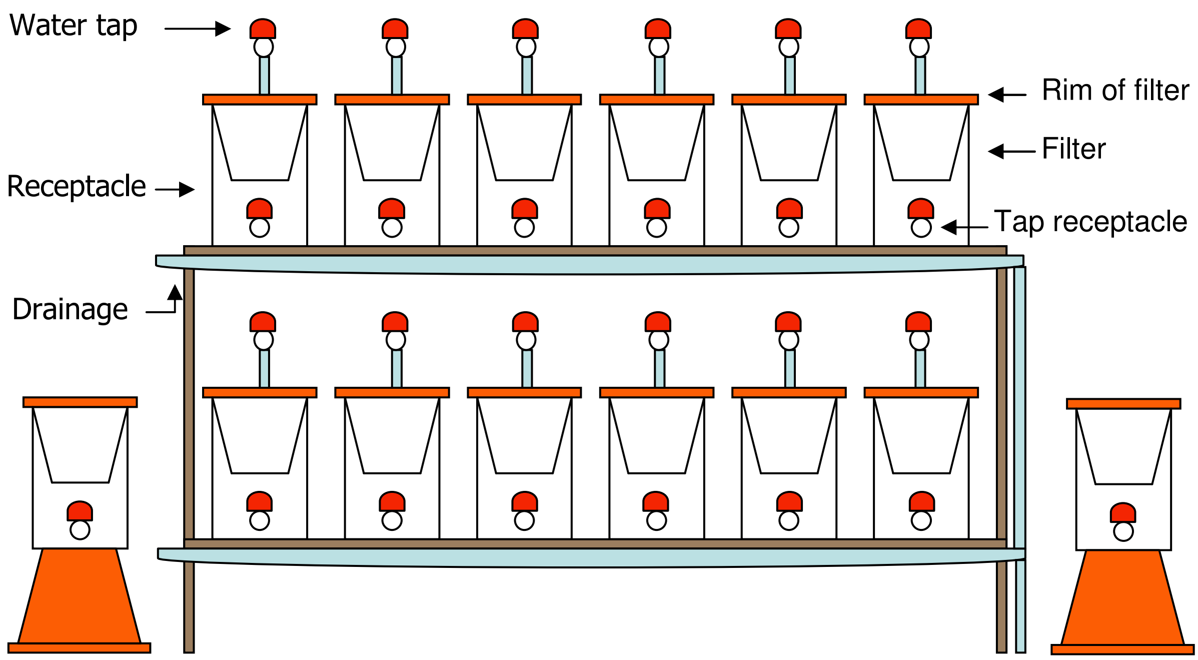


Figure F.1: Schematic drawing of set-up

There are 5 action items which has to be done:

1. Filling up the filters
2. Spiking and taking samples
3. Cleaning the filters
4. Measuring the flowrates of the filters
5. Taking silver samples

These 5 action items are described in detail below. The action item will be done on different days. In Table E.1 an overview of action items per day can be seen. The number between the brackets is the number of the action item. A more detailed scheme can be found in Appendix F.1.

Table F.1: Overview action items per day

Day		Action item; for all filters 'tested' that week (7)	Action item; for all filters not 'tested' that week (7)
Monday	Morning	Cleaning (3)	Filling up filters (1)
	Afternoon	Filling up filters (1)	Filling up filters (1)
Tuesday	Morning	Filling up filters (1)	Filling up filters (1)
	Afternoon	Silver samples (5) + filling up filters (1)	Filling up filters (1)
Wednesday	Morning	Filling up filters (1)	Filling up filters (1)
	Afternoon	Filling up filters (1)	Filling up filters (1)
Thursday	Morning	Spike filters (2)	Filling up filters (1)
	Afternoon	Filling up filters (1)	Filling up filters (1)
Friday	Morning	Filling up filters (1)	Filling up filters (1)
	Afternoon	Measure flowrates (4) + filling up filters (1)	Filling up filters (1)

1. Filling up the filters

This action item is done *twice every day*: in the morning (8.30 AM) and in the afternoon (4.30 PM).

How to fill up the filters?

- Open water taps and fill up the filters to the rim (of the filter); close water taps.
- Open taps of the receptacles
- The two filters not in the racks have to be filled manually. Open one of the taps in the racks and use the yellow bucket to fill the two filters not in the racks.

In Figure F.2, the filling up is shown in schematic steps:

Filling up the filters

Open water tap

↓

Fill up filter to the rim, close water

↓

Open receptacle tap
BUT keep it closed at action item 2, 3, 4 and 5

Figure F.2: Filling up the filters

2. Spiking

This action item is done once every week for 7 filters. One week all filters without silver (7 filters) are spiked, the next week, the filters with silver (7 filters) are spiked. The following week filters without silver are spiked again. Spiking is always done on a Thursday. Filters that are not spiked that week are normally filled up in the morning and afternoon. The filters that are spiked that particular day are filled up in the morning with the spiked solution which is mixed in the mixing tank. In the afternoon they are filled up with water from the tap (the regular way).

How to spike the filters?

7 bottles of 100 ml with 10^5 cfu/ml of E.coli B and 10^6 pfu/ml of MS2 are prepared in the morning when spiking the filters *without* silver. 7 bottles with 10^6 cfu/ml of E.coli B and 10^6 pfu/ml of MS2 will be provided, when spiking the filters *with* silver. How these dilutions are made can be found in Appendix F.2.

- Empty the receptacles of the filters that will be spiked that day (7 filters with silver or the 7 filters without silver) completely: take off filter, pour out water. If you spike the filters with silver, dry/wipe the bottom and side walls of the receptacle after emptying with clean paper towel wearing (clean) gloves. Wiping is necessary because silver may have been adsorbed at the plastic walls. Also check bottom of filters for biofilm (thin green layer), if present (more chance for filters without silver) remove with clean paper towel wearing gloves. Close tap of receptacle and put the filter (including plastic ring) back on the receptacle.
- Fill up the 'mix tank' to the 20L line. While filling up check T (with hand) of water. The water in the pipelines can reach high temperatures when heated by the sun. When spiking water with a high temperature this will decrease the number of bacteria and viruses, which is undesirable. Therefore, make sure that you get rid of all the hot water in the pipelines. Empty the receptacle and fill up with 20L 'cold' water.

- For 20L, add 2 bottles of 100ml containing the concentrated solution of E.coli and MS2. Make sure you add all of the solution. (Per 10L, 1 bottle of 100ml of spiked solution is added).
- Mix the 20L of tap water + 2*100ml concentrated solution for 15 minutes with the blue rod. Stir firmly.
- After 15 minutes take a sample of the water in the mix tank. A sample is taken with a sterile plastic bottle (provided by the Lab). This bottle must be labeled with the date, with IN (because this solution will be poured IN the filters) and the name/ID of the two filters to which this solution will be added.
- Gently pour 10L in each of the two filters (fill up to the rim; the ID's of these 2 filters is written down on the sample bottle) using the yellow bucket. Be very carefully. Do not spill over the rim. The spiked solution must end IN the filter, not be spilled and end directly in the receptacle. Results then, might be misinterpret.
- After the 2 filters are filled up with the spiked solution, rinse the mix tank. Fill the mix tank again with 20L, but again check the temperature, before adding the 100ml concentrated solution.

In Figure F.3, the spiking is shown in schematic steps:

Spiking

Empty receptacle

↓ Wipe / dry bottom filters

Fill mix tank up to 20L line

↓ Check T_{water}

Add 2*100ml of concentrated spiked solution

↓ If 10L, add 1*100ml

Mix 20L for 15 minutes

↓ If 10L, mix for 7.5 minutes

Take sample, bottle labeled with IN,
date and ID’s of filters

↓

Fill each filter with 10L (up to the rim)

Figure F.3: Steps of spiking

In total 3 times 20 liters is mixed and 1 time 10L, because in total 7 filters are spiked. The 10L is mixed for 7.5 minutes.

3. Cleaning the filters

Filters are cleaned once every two weeks. One week all filters without silver (7 filters) are cleaned, the next week, the filters with silver (7 filters) are cleaned. Filters are always cleaned on Mondays. Therefore always close the taps of the receptacles when filling up on Friday in the afternoon as the filtered water is necessary for the cleaning. A detailed description, how to clean according to description of RDI, can be found in Appendix F.3.

How to clean?

- Make sure that on Friday when you fill up in the afternoon, the taps of the receptacles are closed. The filtered water is needed for cleaning.

Cleaning receptacle / plastic container:

- Take off filter from receptacle.
- Add soap to receptacle and clean the receptacle with soap by brushing the inside (bottom and walls).
- Empty receptacle and rinse out soap with some water from water tap.
- Place emptied receptacle in SUN. Let it dry until completely dry. Sun will kill all micro organisms.

Cleaning ceramic water filter:

- Take big blue plastic bowl from Lab and place outside. Fill this with about 15L DI water from Lab.
- Place filter in bowl filled with water and brush the inside / outside / walls and bottom of the filters with small plastic brush.
- Place filter on a safe and clean place.
- Clean the plastic ring.

- If the receptacle is dry, place the filter back in the receptacle. Be sure that the ID on the filter is matched the ID written on the receptacle.
- Place the receptacles with filters back in the racks

In Figure F.4 the steps are repeated.

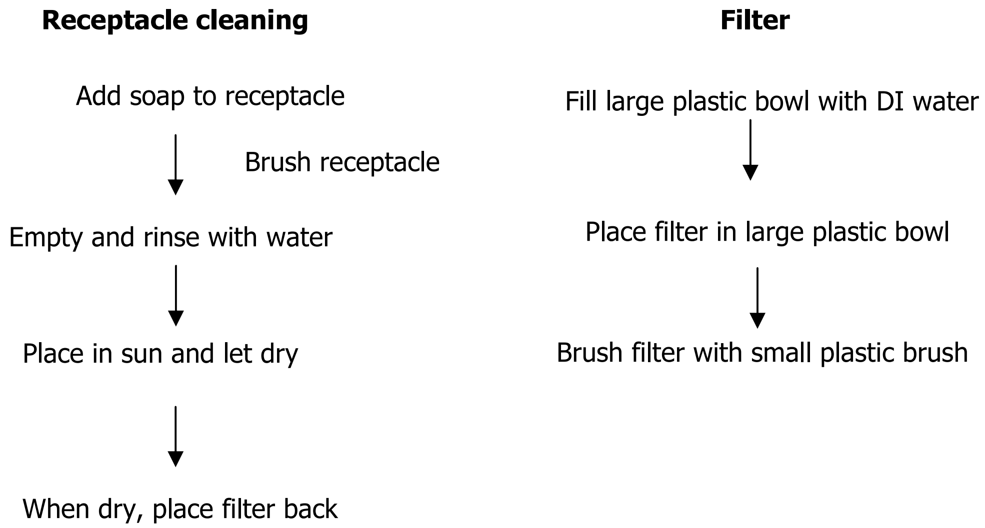


Figure F.4: Cleaning steps

4. Measuring the flowrate

The flowrate of the filters are measured once every two weeks. One week the flowrate of all the filters without silver (7 filters) are measured, the next week, the flowrate of the filters with silver (7 filters) are measured. Flowrates are always measured on Fridays.

How to measure the flowrate?

- Empty receptacle; to make a accurate measurement the receptacle must not contain any water
- Close tap of the receptacle
- Fill filter up to the rim (t = 0)
- Wait for 27 minutes, then start emptying the water that is still in the filter. When empty enough, take the filter out of the receptacle. Empty the filter completely and place on clean and safe place. To this for all filters you filled up at t = 0.
- Measure the water in the receptacle by pouring it in a measuring beaker.
- Write down the amount of water together with the date, the ID of that particular filter and the total throughput of the filter.

TIP: Measure the flowrate of 3 or 4 filters at the same time. This means, fill them up at the same time and empty them at the same.

In Figure F.5, a schematic overview of the flowrate measurement can be found.

Measuring flowrate

Empty receptacle

↓

Close receptacle tap

↓

Fill filter up to the rim (t = 0)

↓ Time with stopwatch

After 27 minutes, empty water in filter

↓

Store filter on safe and clean place

↓

Measure water in receptacle with beaker

↓

Write down volume, filter ID, date and throughput

↓

Place filter back in receptacle

Figure F.5: Measuring the flowrate

5. Taking samples for silver concentration measurements

This action item is done every week, only for the filters painted with silver. This action item is done on Tuesdays.

How to take the silver samples?

- Close receptacle tap when filling the filter up on Tuesday morning
- When enough water is filtered through the filter into the receptacle, take a sample a clean plastic bottle. This bottle does not have to be sterile; the bottles can be found at experimental set-up.
- On this bottle write down the date, ID of the filter and the throughput

In Figure F.6, a schematic overview of the silver samples can be found

Silver samples

Close receptacle tap

Fill up

When enough water in receptacle, take sample in clean plastic bottle

Write down ID of filter, date and throughput

Figure F.6: Silver samples

F.1: Schedule

Date		All filters no silver	All filters silver
Monday	Morning	430	**Cleaning**
31-mrt	Evening	440	410
Tuesday	Morning	450	420
			Sample
1-apr	Evening	460	430
Wednesday	Morning	470	440
2-apr	Evening	480	450
Thursday	Morning	490	**460 Spiking**
3-apr	Evening	500	470
Friday	Morning	510	480
			Flowrate
4-apr	Evening	520	490

Date		All filters no silver	All filters silver
Monday	Morning	**Cleaning**	500
7-apr	Evening	530	510
Tuesday	Morning	540	520
8-apr	Evening	550	530
Wednesday	Morning	560	540
9-apr	Evening	570	550
Thursday	Morning	**580 Spiking**	560
10-apr	Evening	590	570
Friday	Morning	600	580
		Flowrate	
11-apr	Evening	610	590

Date		All filters no silver	All filters silver
Monday			
14-apr			
Tuesday			
15-apr			
Wednesday	Morning	620	**Cleaning**
16-apr	Evening	630	600
Thursday	Morning	640	**610 Spiking**
17-apr	Evening	650	620
Friday	Morning	660	630
			Flowrate
18-apr	Evening	670	640

Date		All filters no silver	All filters silver
Monday	Morning	**Cleaning**	650
21-apr	Evening	680	660
Tuesday	Morning	690	670
22-apr	Evening	700	680
Wednesday	Morning	710	690
23-apr	Evening	720	700
Thursday	Morning	**730 Spiking**	710
24-apr	Evening	740	720
Friday	Morning	750	730
25-apr		**Flowrate**	
	Evening	760	740

Date		All filters no silver	All filters silver
Monday	Morning	770	**Cleaning**
28-apr	Evening	780	750
Tuesday	Morning	790	760
29-apr			**Sample**
	Evening	800	770
Wednesday	Morning	810	780
30-apr	Evening	820	790
Thursday	Morning	830	**800 Spiking**
1-mei	Evening	840	810
Friday	Morning	850	820
2-mei			**Flowrate**
	Evening	860	830

Date		All filters no silver	All filters silver
Monday	Morning	**Cleaning**	840
5-mei	Evening	870	850
Tuesday	Morning	880	860
6-mei	Evening	890	870
Wednesday	Morning	900	880
7-mei	Evening	910	890
Thursday	Morning	**920 Spiking**	900
8-mei	Evening	930	910
Friday	Morning	940	920
		Flowrate	
9-mei	Evening	950	930

Date		All filters no silver	All filters silver
Monday	Morning	960	**Cleaning**
12-mei	Evening	970	940
Tuesday	Morning	980	950
13-mei			**Sample**
	Evening	990	960
Wednesday	Morning	1000	970
14-mei	Evening	1010	980
Thursday	Morning	1020	**990 Spiking**
15-mei	Evening	1030	1000
Friday	Morning	1040	1010
16-mei			**Flowrate**
	Evening	1050	1020

Date		All filters no silver	All filters silver
Monday	Morning	**Cleaning**	1030
19-mei	Evening	1060	1040
Tuesday	Morning	1070	1050
20-mei	Evening	1080	1060
Wednesday	Morning	1090	1070
21-mei	Evening	1100	1080
Thursday	Morning	**1110 Spiking**	1090
22-mei	Evening	1120	1100
Friday	Morning	1130	1110
		Flowrate	
23-mei	Evening	1140	1120

F.2: Lab work

Spiking solutions
Every Thursday 7 filters will be spiked. For the spiking 7 bottles with 100 ml of concentrated E.coli and MS2 must be prepared. When spiking the filters *with* silver, the concentration spiked is higher than the spiking solutions for the filters without silver. How to prepare the concentrated 100 ml for the filters with and without filters can be found in Figures F.2A and F.2B; the 100 ml solutions is the solution in the dotted lines. The 100 ml will eventually be added to 10L water (last step in Figures F.2A and F.2B).

In Appendix F.1 it can be seen which spiking solution has to be prepared, because this depends on which filters are spiked.

SPIKING for filters without silver

Stock solution E.Coli strain B
10^8 cfu/ml

1 ml in 99 ml ↓ 100 x

10^6 cfu/ml

10 ml in 90 ml ↓ 10 x

10^5 cfu/ml

100 ml in 10 L ↓ 100 x

10^3 cfu/ml

Stock solution MS2
10^{11} pfu/ml

1 ml in 99 ml ↓ 100 x

10^9 pfu/ml

1 ml in 9 ml ↓ 10 x

10^8 pfu/ml

1 ml in 99 ml ↓ 100 x

10^6 pfu/ml

100 ml in 10 L ↓ 100 x

10^4 pfu/ml

89 ml water
10 ml 10^6 cfu/ml
1 ml 10^8 pfu/ml

Final concentration spiked

Figure F.2A: Dilutions for spiking of filters without silver

SPIKING for filters with silver

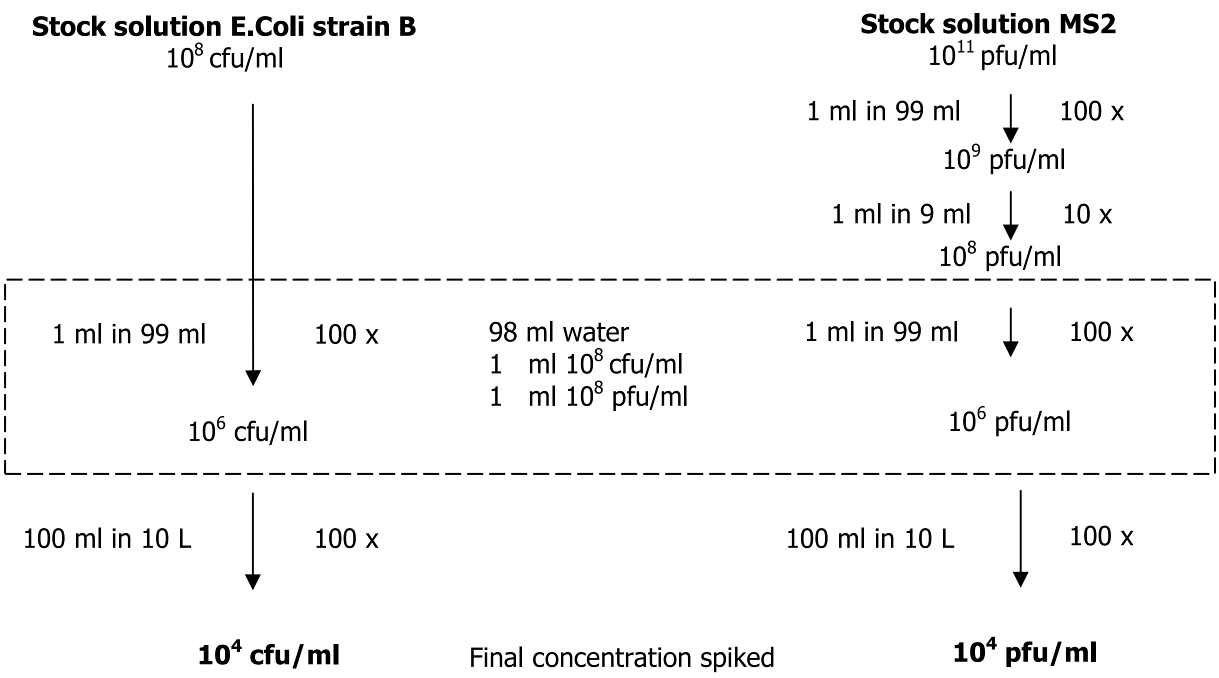


Figure F.2B: Dilutions for spiking of filters with silver

E.coli measurements
Rapid agar or Hi-chrome can be used as agar.

Different dilutions, sample size are measured for filters with respectively without silver. One week filters with silver are measured, the next week the filters without silver etc.

Filters without silver
In total there are 4 IN samples.
Samples of 0,1 ml of 10^{-1} are used for membrane filtration.
All samples are measured in duplo.
TOTAL: 2*4 = 8 plates

In total there are 7 OUT samples.
Samples of 100 ml (not diluted) are used for membrane filtration.
All samples are measured in duple
TOTAL: 2*7 = 14 plates

TOTAL: 22 plates

Filters with silver
In total there are 4 IN samples.
Samples of 0,1 ml of 10^{-2} are used for membrane filtration.
All samples are measured in duplo.
TOTAL: 2*4 = 8 plates

In total there are 7 OUT samples.
Samples of 1 ml (not diluted) are used for membrane filtration.
All samples are measured in duple
TOTAL: 2*7 = 14 plates

TOTAL: 22 plates

Spot titer
C3000 or F-amp can be used as LPH. Mention which LPH one is used in the results-sheet.
Dilutions of $2*10^{-1}$ are used for IN and OUT samples. All samples are done in duplo.

1 ml of sample in 9 ml DI water: 10^{-1}
3 ml of 10^{-1} in 3 ml DI water: $2*10^{-1}$

IN: 4 samples
In duplo: 2*4 = 8 plates

OUT: 7 samples
In duple: 2*7 = 14 plates

In total 22 plates

F.3: Cleaning a Ceramic Water Filter

This education brochure is designed for use in education programmes and demonstrations. It should be learnt by filter sales people, teachers and educators. In this form it is not designed for community members. A simplified, pictorial version will also be developed.

You will need:

A. RDIC Ceramic Water Filter System, comprised of:

1. Ceramic Filter Element

2. Plastic Receptacle

3. Plastic receptacle lid

4. Scrubbing brush

B. Additional items including:

5. Large plastic bowl (kuntong)

The bowl will be used to store clean water during the cleaning process and to hold the filter during cleaning.

6. Soap or detergent

A. First Use - when you take it home

1. Attach the faucet as shown.
2. Fill the ceramic insert and allow it to pass through the filter 2 times and dispose of the water.
3. Clean the filter before you use it using steps shown below.

B. Preparation

1. Filter 20L of water by filling the ceramic insert 2 times, and collecting the water in the plastic receptacle.
2. Boil a tea kettle of water for 15 minutes.

3. Wash your hands with soap and water.

4. Clean the large plastic bowl with filtered water and detergent. Rinse the bowl well.

5. Clean the scrubbing brush with filtered water and soap OR by boiling the scrubbing brush in water for 15 minutes.

C. Clean Lid

6. Remove plastic receptacle lid. Scrub the inside of the lid with scrubbing brush and soap using a small amount of filtered water. Pour excess water onto ground.

7. Rinse the lid with a small amount of filtered water and place lid top side facing up on a table in a safe position.

D. Clean and Dry Plastic Receptacle

8. Pour half the remaining filtered water into the large plastic bowl for storage.

9. Add soap to the water in the plastic receptacle and scrub thoroughly with the scrubbing brush.

10. Pour the water onto the ground.

11. Pour ½ the water from the large plastic bowl into plastic receptacle, rinse and dispose.

12. Rinse the plastic receptacle with boiling water from the tea kettle. Refill the kettle and boil for a further 15 minutes.

13. Set the plastic receptacle in the sun to until the inside surface of the container is completely dry. Avoid areas where dust or dirt will enter the container.

E. Clean the Ceramic Insert

14. Place the ceramic insert into the large plastic bowl.

15. FIRST - scrub the OUTSIDE of the ceramic insert thoroughly with the scrubbing brush to remove any biofilm growth. You can tip the filter but do not allow water to enter the filter at this stage.

16. Rinse the outside surface of the ceramic filter element within the large plastic bowl.

17. Place the ceramic insert onto the plastic receptacle lid.

18. SECOND - scrub the INSIDE of the ceramic insert to unclog pores and remove grit.

19. Pour water out of large plastic bowl into the ceramic insert and scrub very well.

20. Pour the water onto the ground and repeat several times until the water is clear.

F. Final Clean and Reassembly

21. When the plastic receptacle is completely dry, return it to a safe and secure location and pour one tea kettle of boiling water onto the ceramic insert.

22. Replace the ceramic filter element (with fitting ring) into the plastic receptacle.

23. Replace the plastic receptacle lid.

RDIC 180308

APPENDIX E

This Appendix contains information on the membrane filter and the two agars used to detect *E.coli*.

Membrane filter

Description: MF-Millipore Membrane, mixed cellulose esters, Hydrophilic, 0.45 µm, 47 mm, white, gridded

Trade Name: MF-Millipore

Gravimetric Extractables, %: 2.5

Filter Color: White

Filter Code: HAWG

Air Flow Rate, L/min x cm^2: 4

Filter Brand Name: MF-Millipore

Thickness, µm: 180

Filtration Device and Accessory Type: Filter Discs/Sheets

Bubble Point at 23 °C: ≥2.2 bar, air with water

Max Operating Temperature, °C: 75

Filter Surface: Gridded

Water Flow Rate, mL/min x cm^2: 60

Wettability: Hydrophilic

Filter Diameter, mm: 47

Filter Pore Size, µm: 0.45

Filter Type: Screen filter

Filter Material: Mixed Cellulose Esters

Refractive Index: 1.51

Porosity %: 79

APPENDIX F

Spot titer method

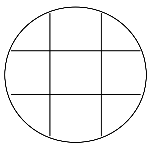
1. Prepare Log Phase Host (LPH)
- 25 ml TSB (Tryptic Soy Broth; 3 g per 100 ml, Becton, Dickinson and Company)
- Add 1 ml of antibiotics (streptomycin/ampicillin (S/A)
- Add 0,1 ml of overnight *E.coli F-amp*

   Grow for 3 – 4 h at 37°C
2. Prepare TSA

   For 100 ml is needed:
- 0,8 g Agar bacto (Becton, Dickinson and Company)
- 3 g Tryptic Soy Broth (TSB)

   Calculate 5 ml of TSA per plate
   Heat and stir till clear solution and autoclave the TSA prepared
   When TSA is autoclaved put the solution in a water bath at 42°C
3. Prepare Petri dishes

   At the bottom part of each disc draw a grid:



   Write sample, date and dilution on the top of the Petri dish.
   Clean a spot and order the Petri dish.

4. Prepare dilutions of the samples

   First start with dilutions of 10^{0}, 10^{-1}, 10^{-2} for in and output samples. Next time you do the spot titer for the same samples you know more or the less in which range you are. Duplo's of the same dilutions are preferred.
5. LPH out of incubator

   After 3 – 4 hours get the LPH out of the incubator. Check for growth of the bacteria (more turbid solution). Check the temperature of the TSA in the water bath. If still higher than 45 °C, wait till temperatures drops further down. When adding the LPH at temperature above 45°C the bacteria may die. But at a temperature below 40°C, the agar will become solid. A good temperature controlling device is thus important.
6. Prepare TSA with S/A and LPH

   When the temperature is 42 – 44 °C add the following:
- 1 ml S/A per 100 ml TSA; carefully mix solution by shaking TSA
- 4 ml LPH per 100 ml TSA; carefully mix solution by shaking TSA

7. Pour or pipet 5 ml of the TSA solution (with S/A and LPH) in every prepared dish. Prepare also some spare dishes in case a mistake is made.
8. Wait until the agar becomes solid in the dish, this will take only a few minutes. Then pipet 0,01 ml (a 'spot') on each grid (9 in total) from the (diluted) sample. Always start with the most diluted sample of the same sample. Then you can use the same pipet for 10^{-2} to 10^{0}.
9. Do not close the Petri dishes, but let the spots dry in the air; a biosafety spot preferred.
10. When dried put the samples inverted in the incubator. Incubate them at 37°C for about 16 – 24h.