Report

Removal efficiency of Silver impregnated Ceramic filters

A study of the removal of pathogenic bacteria.

Basic information:

A new ceramic filter utilizing a siphon system, developed by Basic Water Needs India, includes a nano silver treated candle as the filter element. This filter element was tested on removal of bacteria. In this test, filters impregnated with silver were compared with reference filters without silver impregnation.

Conclusions:

- After passing of 7.000 liter of water the silver impregnated filters still reduce E coli bacteria by more than 99.99% (log 4.5 to 5.5).
- The removal capacity of silver impregnated filters is significant higher than filters without silver, especially after 5.500 liter.

Experiments:

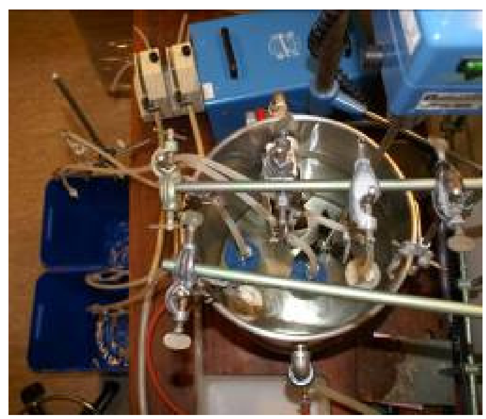
The filters were tested with known concentrations of bacteria. The bacteria strain used was E. coli WR1. This microorganism is also used in the Dutch guidelines for Quantitative Microbiological Risk Analysis. The E.coli WR1 is used as an indicator for the removal of pathogenic bacteria in surface water. The E. coli used as influent had a concentration of 10^6 CFU/liter.
Experiments were carried with a flow rate of 6 liter/hour and 3 liter/hour.
To get information resembling the use in practice and to reduce the time needed for testing to two weeks, the following procedure was used.

After the first dose of microorganism a pump created a flow rate of 50l/hour. In this way 1.000 liter of water is passed through the filter. After this flushing, the filter was scrubbed with a Scotchbrite pad and the filter diameter was measured. Scrubbing removes a small layer of the outside filter element material.
After every 1.000 liter of flushing the ceramic filter is scrubbed, and the filter element is measured
Then contaminated water is passed and the removal of E. coli and the concentration silver in the effluent water was measured.
This was done until 8.000 liter of water was flushed through the filter.
By using a maximum flush flow rate the time needed for these tests was reduced from several months to a few weeks.

Test set-up

1 Ceramic filters are placed in a 50 liter container
2 Water is flushed through the filter at a flow-rate of 3 and 6 liter/hour
3 The diameter of the filter is measured (in mm)
4 E.coli is added at a final concentration of 1,000,000 cfu/l
5 Before the start the concentrations are checked (by sampling the water)
6 After 10 liter has flown through, a sample of 500 ml is analyzed.
7 The filter is connected to a pump and maximum flow is used to pump 1.000 liter water through the filter.
8 The filter is cleaned by scrubbing the outside with a Scotchbrite pad and the diameter of the filter is measured again
9 The filters are flushed through with 10 liter clean, bacteria free water.
10 At the end a 500 ml sample is taken for analysis (blank)
11 Than the filters are placed again in the container with E.coli
12 Steps 5, 6, 7, 8, 9, 10 and 11 are repeated.
13 This is done till a total of 8.000 liter is flown through the filters.

Every time a concentrated volume of microorganisms was used, the concentration was measured (total of 8 times).



Interpreting the measurements:

The results of the analysis can be used to determine the reduction of the microorganisms by the filter.
The reduction is presented as the DEC (Decimal Elimination Capacity) value of the filter. This is expressed in the logarithm value of the reduction

Example:

90%	reduction	DEC =1.0
99%	reduction	DEC =2.0
99.9%	reduction	DEC= 3.0

Reliability of the results:
All the microbiological analyses were according to certified methods.

- E. coli according to NEN-ISO 9308-3

In the tests 2 filters were impregnated with silver and 2 filters were not.
The filters were tested at two different flow rates.
Because of the small number of filters tested it was not possible to give statistical calculations or interpretations of the results.

Wall thickness filter at end of tests

Results:

In table 1 the results of the measurements are presented. The removal of E.coli, the diameter of the filter and the silver concentration of the water coming out of the filter are given. After the last experiments the filter element was cut and the remaining thickness of the wall was measured. With that information and the diameters of the filters, the changing of the thickness of the ceramic wall during the dose experiments can be estimated (appendix table 3).

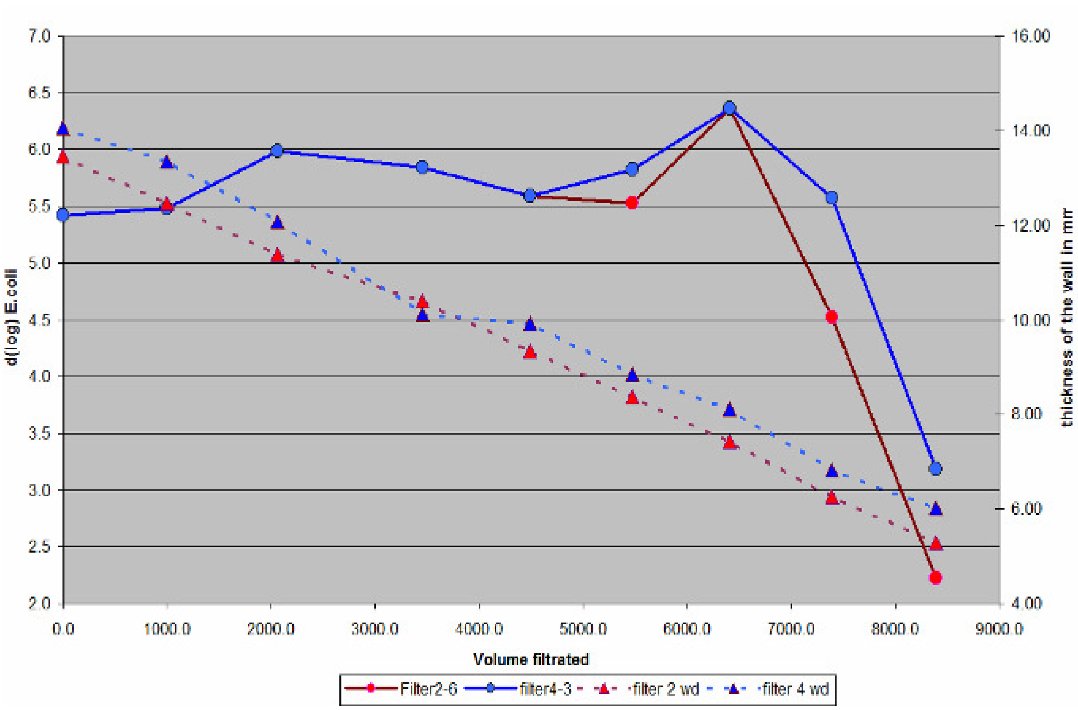
Table 1: Results of reference filters and silver treated filters at variable flow-rates.

		Filter 1	Filter 2	Filter 3	Filter 4
Filtertype ->		reference	Silver	Reference	Silver
Flow-rate (l/h)		6	6	3	3
start	Diameter (cm)	5.54	5.59	5.57	5.63
	Ag (ug/liter)	<1	11.95	<1	17.68
	d(log) E.coli	**5.1**	**>5.4**	**>5.4**	**>5.4**
after1000 liter	Diameter (cm)	5.49	5.49	5.52	5.56
	Ag (ug/liter)	<1	10.45	<1	14.16
	d(log) E.coli	**4.4**	**5.5**	**5.5**	**5.5**
after 2067 liter	Diameter (cm)	5.35	5.38	5.36	5.43
	Ag (ug/liter)	<1	9.94	<1	12.92
	d(log) E.coli	**5.2**	**>6.0**	**6.0**	**>6.0**
after 3452 liter	Diameter (cm)	5.25	5.28	5.26	5.23
	Ag (ug/liter)	<1	3.9	<1	10.1
	d(log) E.coli	**5.5**	**>5.8**	**>5.8**	**>5.8**
after 4487 liter	Diameter (cm)	5.15	5.15	5.16	5.21
	Ag (ug/liter)	<1	3.57	<1	11.45
	d(log) E.coli	**5.1**	**>5.6**	**>5.6**	**>5.6**
after 5469 liter	Diameter (cm)	5.05	5.08	5.05	5.1
	Ag (ug/liter)	<1	3.89	<1	8.57
	d(log) E.coli	**3.8**	**5.5**	**4.9**	**>5.8**
after 6411 liter	Diameter (cm)	4.95	4.99	4.96	5.03
	Ag (ug/liter)	<1	2.8	<1	8.56
	d(log) E.coli	**3.7**	**>6.4**	**4.5**	**>6.4**
after 7390liter	Diameter (cm)	4.84	4.87	4.92	4.90
	Ag (ug/liter)	<1	1.32	<1	5.5
	d(log) E.coli	**2.7**	**4.5**	**2.9**	**5.6**
after 8389 liter	Diameter (cm)	4.74	4.77	4.85	4.82
	Ag (ug/liter)	<1	1.72	<1	3.65
	d(log) E.coli	**1.1**	**2.2**	**1.2**	**3.2**

Discussion:

One has to be aware that these are results of two silver impregnated filter elements, so this is a first indication of what these type of filters are capable of achieving in terms of performance. For a more representative proof, more filters randomly taken from the production should be tested to confirm reliability. Bacteria removal capacity of silver impregnated filters is significant and higher than the reference filters without silver, especially after 5.500 liter.
As expected the silver impregnated filters showed a higher reduction of E.coli. In the beginning of the test all filters removed almost totally the added E. coli, which was between 100.000 and 1.000.000 per ml.
Reference filter 1 (without silver) with a flow rate of 6 liter/hour was the first filter in which some E. coli came through after passing a few liters of water. Reference filter 2 with a flow rate of 3 liter/hour (filter 3) leaked E.coli after 5.000 liter.
The first silver-impregnated filter which leaked E.coli was filter 2 (flow-rate of 6 liter /hour) and this was also after 5.000 liter. Filter 4 (silver impregnated and a flow rate of 3 liter/hour) gave first signs of leakage after more than 7.000 liter of water.
Filter 2 had a sporadic E.coli in the effluent after 5.000 liter but after 6.500 liter no E.coli was spotted in the effluent. The measurement after 5.000 liter possibly could be an artefact of the experiments.

Figure 1: Removal of E.coli and wall thickness of silver-impregnated filters



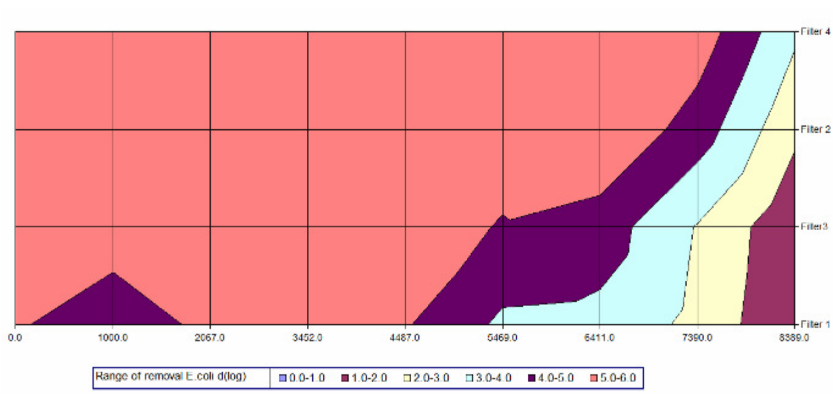
In figure 1 the relation between removal of E.coli and the diminishing thickness of the ceramic wall is shown. Although there are more differences between both filters (as flow-rate and silver concentration) there seems to be a clear effect on the E.coli removal related to the thickness of the wall. This relation seems much more evident than other factors.

The content of the silver in the impregnated filters seems high enough, even after 7.500 liter, to effectively eliminate high concentration E. coli. Note that the bulk volume of the 7.000 liter was not heavily contaminated with bacteria. For flushing, drinking water at a flow-rate of 50 l/hour was applied. In practice it could be that in heavily contaminated water with more bacteria the silver in the filters is “consumed” which can shorten the lifetime. Further tests are needed.

A question is how these filters decrease the amount of viruses since these are much smaller than bacteria. Since the removal of organisms is mainly due to the thickness of the wall it can be expected that the removal of viruses will be lower than of E. coli. On the other hand silver is also effective against viruses and maybe the concentration of the silver is enough to eliminate viruses.

The effect of different flow rate on E. coli removal is not completely clear. Non impregnated filters show a lower bacterial removal at a higher flow rate. After 5.500 liter, the silver impregnated filters had a lower bacterial removal rate at the higher flow rate. In surface water with a high turbidity particle content, the filter gets clogged. In that case the filters have to be scrubbed earlier than after filtering 1.000 liter of water.

Figure 2: removal of E.coli of four tested filters presented in logarithm ranges



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Appendix

Table 2: Raw data measurements E.coli in influent and effluent of the Ceramic Filters

E.coli Most probable number according to NEN-ISO 9308-1

	Sample	10^-1	10^-2	10^-3	10^-4	10^-5	10^-6	10^-7	n/ml	95%low	95%high	R
	Eind-8000	16	16	16	16	16	7	1	5.8	5.5	6.0	9.5E-01
	Filter 4-8000	16	16	5	2	0	0	0	2.7	2.4	3.0	2.7E-01
	Filter 3-8000	16	16	16	16	6	0	0	4.7	4.4	4.9	1.0E+00
	Filter 2-8000	16	16	16	6	0	0	0	3.7	3.4	3.9	1.0E+00
	Filter 1-8000	16	16	16	16	8	0	0	4.8	4.5	5.1	9.4E-01
	Voor 8000	16	16	16	16	16	10	3	6.0	5.8	6.3	4.1E-01
	Eind 7000	16	16	16	16	16	9	0	5.8	5.6	6.1	7.7E-01
	Filter 4-7000	5	1	0	0	0	0	0	0.6	0.3	0.9	6.5E-01
	Filter 3-7000	16	16	12	4	1	0	0	3.2	3.0	3.5	1.0E-01
	Filter 2-7000	16	5	0	0	1	0	0	1.7	1.4	1.9	6.9E-03
	Filter 1-7000	16	16	14	6	1	0	0	3.4	3.2	3.7	1.0E-01
	Voor 7000	16	16	16	16	16	16	5	6.5	6.3	6.8	9.4E-01
	Eind 6000	16	16	16	16	16	5	2	5.7	5.4	6.0	2.6E-01
<	Filter 4-6000	1	0	0	0	0	0	0	-0.2	-1.1	0.6	9.5E-01
	Filter 3-6000	16	5	0	0	0	0	0	1.6	1.3	1.9	1.0E+00
<	Filter 2-6000	1	0	0	0	0	0	0	-0.2	-1.1	0.6	9.5E-01
	Filter 1-6000	16	16	1	0	0	0	0	2.4	2.1	2.7	2.5E-01
	voor 6000	16	16	16	16	16	16	6	6.6	6.3	6.8	8.0E-01
	eind 5000	16	16	16	16	14	5	1	5.4	5.2	5.6	1.7E-01
<	Filter 4-5000	1	0	0	0	0	0	0	-0.2	-1.1	0.6	9.5E-01
	Filter 3-5000	5	2	0	0	0	0	0	0.7	0.3	1.0	2.5E-01
	Filter 2-5000	1	1	0	0	0	0	0	0.1	-0.5	0.7	1.9E-01
	Filter 1-5000	16	8	0	0	0	0	0	1.8	1.5	2.1	9.4E-01
	Voor 5000	16	16	16	16	16	8	0	5.8	5.5	6.1	9.1E-01
	Eind-4000	16	16	16	16	11	3	0	5.1	4.9	5.3	5.9E-01
<	Filter 4-4000	1	0	0	0	0	0	0	-0.2	-1.1	0.6	9.5E-01
<	Filter 3-4000	1	0	0	0	0	0	0	-0.2	-1.1	0.6	9.5E-01
<	Filter 2-4000	1	0	0	0	0	0	0	-0.2	-1.1	0.6	9.5E-01
	Filter 1-4000	2	1	0	0	0	0	0	0.3	-0.2	0.7	2.9E-01
	voor 4000	16	16	16	16	16	4	1	5.6	5.3	5.9	5.5E-01
	Eind -3000	16	16	16	16	10	1	0	5.0	4.7	5.2	1.0E+00
<	Filter 4-3000	1	0	0	0	0	0	0	-0.2	-1.1	0.6	9.5E-01
<	Filter 3-3000	1	0	0	0	0	0	0	-0.2	-1.1	0.6	9.5E-01
<	Filter 2-3000	1	0	0	0	0	0	0	-0.2	-1.1	0.6	9.5E-01
	Filter 1-3000	2	0	0	0	0	0	0	0.1	-0.5	0.7	9.5E-01
	Voor 3000	16	16	16	16	16	1	0	5.4	5.1	5.7	2.5E-01
	Eind 2000	16	16	16	16	11	1	0	5.0	4.8	5.3	1.0E+00
<	Filter 4-2000	1	0	0	0	0	0	0	-0.2	-1.1	0.6	9.5E-01
<	Filter 3-2000	1	0	0	0	0	0	0	-0.2	-1.1	0.6	9.5E-01
<	Filter 2-2000	1	0	0	0	0	0	0	-0.2	-1.1	0.6	9.5E-01
	Filter1-2000	7	2	0	0	0	0	0	0.8	0.5	1.1	4.9E-01
	Voor-2000	16	16	16	16	15	5	0	5.5	5.2	5.7	7.3E-01
	eind-1000	16	16	16	16	15	4	0	5.4	5.2	5.7	1.0E+00
<	Filter4-1000	1	0	0	0	0	0	0	-0.2	-1.1	0.6	9.5E-01
	Filter3-1000	1	0	0	0	0	0	0	-0.2	-1.1	0.6	9.5E-01
<	Filter2-1000	1	0	0	0	0	0	0	-0.2	-1.1	0.6	9.5E-01
	Filter1-1000	5	0	0	0	0	0	0	0.5	0.1	0.9	9.4E-01
	Voor-1000	16	16	16	16	16	11	2	6.1	5.8	6.3	1.7E-01
	eind-0	16	16	16	16	13	5	0	5.3	5.1	5.5	2.8E-01
<	Filter 4-0	1	0	0	0	0	0	0	-0.2	-1.1	0.6	9.5E-01
<	Filter 3-0	1	0	0	0	0	0	0	-0.2	-1.1	0.6	9.5E-01
<	Filter 2-0	1	0	0	0	0	0	0	-0.2	-1.1	0.6	9.5E-01
	Filter 1-0	2	0	0	0	0	0	0	0.1	-0.5	0.7	9.5E-01
	voor-0	16	16	16	16	16	9	1	5.9	5.7	6.2	1.3E-02

Table 3: Raw data of measurement of diameter of ceramic filters

		filter 1 (cm)	filter 2 (Ag) (cm)	filter 3 (cm)	filter 4 (Ag) (cm)
7/apr	diameter 1 a	5.53	5.58	5.57	5.62
	diameter 1 b	5.54	5.59	5.57	5.63
	diameter 1 c	5.54	5.60	5.56	5.63
	diameter gem	5.54	5.59	5.57	5.63
10/apr	diameter 2 a	5.49	5.48	5.53	5.56
	diameter 2 b	5.49	5.49	5.52	5.56
	diameter 2 c	5.50	5.50	5.51	5.55
	diameter gem	5.49	5.49	5.52	5.56
14/apr	diameter 3 a	5.35	5.38	5.36	5.42
	diameter 3 b	5.35	5.38	5.37	5.44
	diameter 3 c	5.35	5.39	5.36	5.43
	diameter gem	5.35	5.38	5.36	5.43
16/apr	diameter 4 a	5.25	5.29	5.26	5.23
	diameter 4 b	5.26	5.29	5.26	5.23
	diameter 4 c	5.25	5.27	5.25	5.24
	diameter gem	5.25	5.28	5.26	5.23
18/apr	diameter 5 a	5.15	5.17	5.16	5.22
	diameter 5 b	5.14	5.18	5.16	5.22
	diameter 5 c	5.15	5.18	5.16	5.20
	diameter gem	5.15	5.18	5.16	5.21
21/apr	diameter 6 a	5.05	5.08	5.05	5.10
	diameter 6 b	5.04	5.08	5.05	5.11
	diameter 6 c	5.05	5.08	5.05	5.11
	diameter gem	5.05	5.08	5.05	5.11
23/apr	diameter 7 a	4.95	4.98	4.96	5.03
	diameter 7 b	4.94	4.99	4.97	5.04
	diameter 7 c	4.95	4.99	4.96	5.03
	diameter gem	4.95	4.99	4.96	5.03
	diameter 8 a	4.85	4.87	4.92	4.89
	diameter 8 b	4.84	4.87	4.91	4.91
	diameter 8 c	4.84	4.87	4.92	4.91
	diameter gem	4.84	4.87	4.92	4.90
	diameter 9 a	4.74	4.76	4.84	4.83
	diameter 9 b	4.73	4.78	4.85	4.81
	diameter 9 c	4.74	4.78	4.85	4.83
	diameter gem	4.74	4.77	4.85	4.82
	Total	0.80	0.82	0.72	0.80

Table 4: Thickness of the ceramic wall of the filters in mm

Flushed volume	F1	F2	F3	F4
0	13.38	13.47	11.58	14.06
1000.0	12.95	12.47	11.11	13.35
2067.0	11.51	11.40	9.55	12.09
3452.0	10.56	10.40	8.48	10.12
4487.0	9.48	9.33	7.51	9.92
5469.0	8.48	8.37	6.41	8.85
6411.0	7.48	7.43	5.55	8.12
7390.0	6.45	6.27	5.11	6.82
8389.0	5.38	5.3	4.38	6.02
Maesurement 1	5.5	5.4	4	6.1
Maesurement 2	5.1	5.1	3.9	6.1
Maesurement 3	5.1	5.2	4.6	5.6
Maesuerement 4	5	5.3	4.8	6
Maesurement 5	6.2	5.5	4.6	6.3
Mean after 8389 liter	**5.38**	**5.3**	**4.38**	**6.02**

Table 5: Removal of E.coli in percentage at different volumes.

		Filter 1	Filter 2	Filter 3	Filter 4
Filtertype ->		reference	Silver	Reference	Silver
Flow-rate (l/h)		6	6	3	3
start	d(E.coli) in %	99.9992	99.9996	99.9996	99.9996
after1000 liter	d(E.coli) in %	99.9963	99.9997	99.9997	99.9997
after 2067 liter	d(E.coli) in %	99.9994	99.9999	99.9999	99.9999
after 3452 liter	d(E.coli) in %	99.9997	99.9999	99.9999	99.9999
after 4487 liter	d(E.coli) in %	99.9992	99.9997	99.9997	99.9997
after 5469 liter	d(E.coli) in %	99.9842	99.9997	99.9988	99.9999
after 6411 liter	d(E.coli) in %	99.9989	99.9990	99.9989	99.9991
after 7390liter	d(E.coli) in %	99.8155	99.9970	99.8861	99.9997
after 8389 liter	d(E.coli) in %	92.0150	99.3976	93.9776	99.9345