Hydraulic Properties Investigation of the Potters For Peace Colloidal Silver Impregnated, Ceramic Filter

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Abstract

This study investigated the hydraulic properties of the Potters For Peace filter in greater detail than previous studies by Sten Eriksen and Daniele Lantagne. Hydraulic properties such as the hydraulic conductivity and tortuosity are important because they help determine the contact time of pathogens in the water with silver to provide inactivation. Two laboratory tests were conducted using both experimental and numerical methods for attaining the results. Unfortunately, the hydraulic conductivity results were questionable for many reasons and the tortuosity results varied considerably due to the porosity variability results. This research does not conclusively describe the hydraulic properties for the PFP ceramic filter, but it does have model improvements and many recommendations for future research. Future work resulting from this research will hopefully lead to accurate and conclusive results about the hydraulic properties of this economically feasible and effective filter.

Keywords

Engineers Without Borders, Potters For Peace, Filtrón, Appropriate technology, ceramic filter, colloidal silver, developing countries, drinking water, point-of-use treatment.

Executive Summary

INTRODUCTION

The Potters for Peace colloidal silver impregnated ceramic filter is an affordable sustainable technology for treating drinking water in individual homes of developing communities. Potters in many countries around the world produce this filter, the Filtrón. The most accomplished workshop is in Managua, Nicaragua.

The purpose of this research is to investigate the hydraulic properties of 5 filters from the Managua workshop. These properties are important because they help determine the contact time of pathogens in the water with silver to provide inactivation. Both experimental and numerical methods were used for the two laboratory tests that were conducted. The first test evaluated the hydraulic conductivity of each filter using various constant flow rates of deionized Boulder, Colorado, tap water. The second test used bromide as a tracer to calculate the tortuosity of pores in the ceramic. Results from this work led to recommendations for future study and improvements to silver application.

BACKGROUND

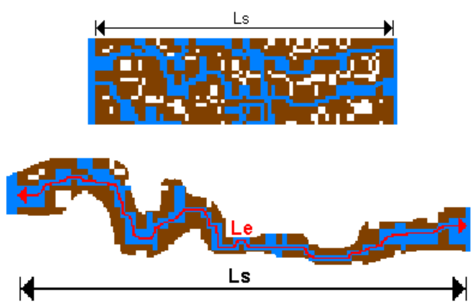
Few studies have extensively evaluated the hydraulic properties of the Filtrón. In 2001, Sten Eriksen produced the first theoretical mathematical model to describe water flow through the filter. Daniele Lantagne conducted an extensive study of both the intrinsic effectiveness in the laboratory and a field study of the filter in Nicaragua, completed in December 2001. She also updated Eriksen's Model. The main technical theories utilized for the research are Darcy's Law and correlations to saturated groundwater contaminant transport.

Table 1 defines the parameters used and Figure 1 illustrates Le and Ls.

Table 1: Parameter Defintions

Parameter	Units	Description
Q	mL/min	Flow through the filter; $Q = KA\frac{\Delta \text{h}}{\text{L}}$
K	cm/min	Hydraulic conductivity (measure of how well water travels through the media)
A	cm^2	Cross Sectional Area of the filter the water travels through
? h	cm	Difference in head between the influent and effluent of the filter
L	cm	Shortest linear length the water travels through the filter
D	cm^2/min	Dispersion coefficient (movement of molecules away from each other); $D = D_m t + a_L v$
$\mathbf{D_m}$	cm^2/min	Molecular dispersion coefficient of the tracer used (bromide)
t	unitless	Tortuosity is the ratio of the actual distance the water travels over the shortest linear length; $t = \frac{Le}{Ls}$
$\mathbf{a_L}$	cm	Longitudinal dispersivity, which is a property of the porous medium and is related to pore structure.
v	cm/min	Theoretical actual velocity of the water through the pores – should not be confused with Darcy's velocity
Le	cm	Theoretical actual distance the water travels
Ls	cm	Shortest linear length the water travels through the filter

Figure 1: Le and Ls Illustration



Previous Studies and Model Comparison

Eriksen assumed the filter to be cylindrical while this research uses the true conical geometry of the filter. Figure 2 shows the cylindrical and conical shape used as well as the parameter definitions such as S, x, r, and so on.

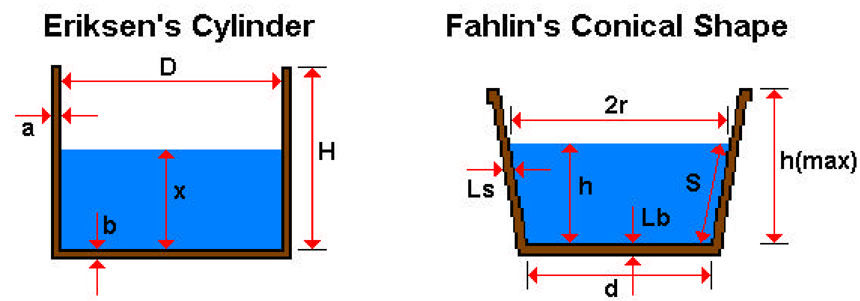


Figure 2: Eriksen and Fahlin Geometric Models Comparison

Eriksen assumed the filter was geometrically cylindrical using the average diameter between the top and bottom. Other key assumptions of both models are summarized in Table 2:

Assumption Categories	Eriksen	Fahlin
Geometry	Cylindrical	Conical
Hydraulic Conductivity	Bottom and side conductivities are equal.	Bottom and side conductivities are different due to dissimilar compression forces during construction.
Head	Same head driving the flow through the bottom as the sides.	Head driving the flow through the bottom and sides is different.
Overall water flow	Batch process (completely filled with no water added).	Continuous flow (water pumped in at constant rates).
Water flow the through sides	Average flow through the sides by integrating Darcy's Law.	No integration since continuous flow was used.

Table 2: Assumption Comparison

Eriksen derived two main equations to describe the flow of the filter for two reasons – (1) to find the actual hydraulic conductivity of the filter and (2) to calculate the theoretical maximum hydraulic conductivity. His model is used to describe the flow of water through the filter when it is initially filled completely, and then allowed to drain.

Table 3: Eriksen Parameter Definitions

Parameter	Units	Origin	Description
k_{actual}	m/hr	Calculated	Actual hydraulic conductivity of the filter
k_{max}	m/hr	Calculated	Theoretical maximum hydraulic conductivity of the filter that should give sufficient silver contact time to inactivate pathogens.
b	m	Measured	Thickness of the filter bottom, which was assumed to equal the thickness on the side
T_{min}	min	Theoretical	Minimum time needed for silver inactivation
T	min	Measured	Time filter operated before x was measured
c	m	Assumed	Thickness of the colloidal silver layer
H	m	Measured	Height of the water inside the filter
D	m	Measured	Average diameter of the filter
x	m	Measured	Distance in height of the water at time of operation after it was filled completely to H.

In Lantagne's work, the experimental pathogen inactivation achieved was significantly greater than predicted by Eriksen. Therefore, Daniele Lantagne reevaluated the Eriksen mathematical model in Section 5.1.2 of *Report 1: Intrinsic Effectiveness* (3). In that section, she explained his model and improved some of his values that he used with the model, but did not make any additions to the model except the tortuosity factor. She improved his time estimate for a filter to completely enter and the thickness of the colloidal silver layer (c) by using an assumed tortuosity. Table 4 is their results.

Table 4: Previous Studies Hydraulic Conductivity Results

	Equation	Units	Eriksen	Lantagne
k_{actual}	$k_{actual} = \frac{b}{T} \ln\left[\frac{H}{x\left(1 + \frac{2H}{D}\right)}\right]$	m/hr	0.03	0.004
k_{max}	$k_{max} = \frac{cb}{T_{min} H}$	m/hr	0.00001	0.0004
ratio	$\frac{k_{actual}}{k_{max}}$	unitless	3000	10

The results in Table 4 show that the actual conductivities were much larger than the actual conductivities leading to the conclusion that the filter has inadequate contact time with silver, but this differs from the empirical removal results of 98 to 100%. Ms. Lantagne's improvements were better estimates of the actual and maximum hydraulic conductivities; however there was still some question about why the filter is so effective and why the theory could not mathematically substantiate it.

METHODS

Both experimental and numerical methods were used for this research. In the lab to ascertain the hydraulic conductivities, the area of filtration was kept constant by using constant flow to simplify the determination of hydraulic conductivities. Also in the lab, bromide was used as a tracer for the first attempt to measure the tortuosity of the filter by recording its breakthrough times. For the numerical methods, graphical analysis and Excel® Solver were used.

DISCUSSION OF RESULTS

The results of this research are not definitive; they are only a beginning for future research. While conducting the hydraulic conductivities test, the filters experienced a clogging phenomenon that hindered the results. The conductivity results were also hindered due to the inadequate side head modeling with Darcy's Law. At best, the hydraulic conductivity results have two results that seem to be logical for two filters. Overall, the hydraulic conductivity results are not similar in magnitude or trends, thus they are inconclusive.

The bromide tracer breakthrough tests are more useful and could be refined with accurate volumetric porosity measurements of the filters used in this research. According to the results, the water remains in the filter for a considerable amount of time. The earliest the bromide tracer could be detected in the initial breakthrough time was 50 minutes at the high flow rate. It is the minimum amount of time the tracer could be detected coming out of the receptacle, not the contact time with silver. The 50 minutes initial breakthrough result is likely to be a good estimate of the minimum amount of time the water is in the pores of the filter.

Assuming this estimation is correct, there should be plenty of time for contact with the silver depending on the thickness of the silver layer. If the silver completely lined the internal pore surface of the filter from the inside to the outside, 50 minutes at a lower concentration of silver currently used by Potters for Peace should be adequate for inactivation. This is assuming that the 25 minute minimum contact time used by Eriksen and the 20 minute contact time from Microdyn (the manufacturer of the colloidal silver) has any merit with regard to a desirable inactivation (such as 99.9%).

The tortuosity results ranged from 4 to 19, but if the overall porosity of the filters were known through experimental analysis these numbers could be refined and quickly determined by using the same spreadsheets constructed for this research. Since the porosities were determined by numerical methods, an estimation of the colloidal silver layer was also determined for each filter. The colloidal silver layer ranged from 2.5 to 10 mm.

Table 5 summarizes all of the Fahlin's results assuming the initial Eriksen Model is valid by comparing the values with Eriksen's initial guess and Lantagne's corrected update.

Parameter	Units	Eriksen	Lantagne	Fahlin	
k_{actual}	m/hr	0.03	0.004	0.00104	0.00287
$k_{max} = \frac{ctb}{T_{min} H}$					
c	m	0.0001	0.0020	0.0025	0.0100
t	-	1	2	4	19
b	m	0.010	0.010	0.0145	0.0145
T_{min}	min	25	25	25	25
H	m	0.24	0.24	0.2034	0.2034
k_{max}	m/hr	0.00001	0.00040	0.00171	0.00325
$\frac{k_{actual}}{k_{max}}$	-	3000	10	0.61	0.89

Table 5: Overall Result Summary Compared to Previous Studies

RECOMMENDATIONS

Unfortunately for Potters For Peace, there is only one immediate recommendation; however, there are recommendations for future research. Hopefully, results from future research will clear-up many uncertainties contained in this research and give Potters For Peace something tangible and more useful in the future.

Both the clogging phenomena and the porosity results indicate that entire pore structure is not fully utilized with a colloidal silver layer. The only recommendation for Potters For Peace is to try new methods of colloidal silver application to fully utilize the entire path of water flow through the filter for contact with inactivating silver. The intended outcome from optimizing the colloidal silver application could be extending the time of use, or life, of the filter by reducing the internal biological clogging while maintaining a high removal percentage and keeping the cost either the same or lower.

There are six future research recommendations. The first three are directly related to this research and last three are not:

1. Repeat the hydraulic conductivity test with slightly different methods ensuring no the filters are covered from light exposure, improved water quality is used, and using all data collected so as not to assume a linear relationship between flow rate and area.

2. Model the side head so Darcy's Law could be used more accurately.

3. Directly measuring the overall volumetric porosity of each filter used in this research so already collected data could be fully utilized to accurately solve for the tortuosity and colloidal silver layer thickness.

4. Determine the Contact Time (CT) for Microdyn's colloidal silver inactivation of pathogens to optimally use the colloidal silver resource i.e. less or more silver with enhanced performance (better inactivation with less clogging).

5. Silver stripping research to determine a silver effluent concentration that could be supported and connected by the CT research.

6. Electron Microscope research of the bottom and side pores structure of the filters used in this research since only a lip of a filter has previously been analyzed.

CONCLUSION

This research is a building block for future research and analysis of the hydraulic properties of the Potters For Peace colloid silver impregnated, ceramic filter. The initial goals were to find the hydraulic conductivities and tortuosity of the five filters tested. Unfortunately, the hydraulic conductivity results were questionable for many reasons and the tortuosity results varied considerably due to the porosity variability. However, there are some important conclusions found in this study as described below:

- Hydraulics of the filter are complex. This research developed an improved model of the actual conical shape of the filter so it is more applicable to the specifics of the constructed filters.
- Some clogging phenomenon occurred over time in the lab, which is also likely to occur in user homes. This is likely attributed to partial utilization of colloidal silver in the pore structure leaving room for biological growth on the non-lined surface of the pores.
- Further testing of colloidal silver inactivation and hydraulics is needed.

This research may not conclusively describe the hydraulic properties for the PFP ceramic filter, but it does have model improvements and many recommendations for future research. Future work resulting from this research will hopefully lead to accurate and conclusive results about the hydraulic properties of this economically feasible and effective filter.