

EVALUATION OF SMALL SYSTEM FILTRATION TECHNOLOGIES FOR THE TREATMENT OF COLOR, DISINFECTION BYPRODUCTS AND MICROBIOLOGICAL CONTAMINANTS IN SURFACE WATERS

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This report was compiled in cooperation with Shaw Environmental, Inc.
Under EPA Contract EP-C-04-034, Work Assignment No. 0-03

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March 31, 2010

Notice

The U.S. Environmental Protection Agency, through its Office of Research and Development, funded and managed, or partially funded and collaborated in, the research described herein. It has been subjected to the Agency's peer and administrative review and has been approved for publication. Any opinions expressed in this report are those of the author (s) and do not necessarily reflect the views of the Agency, therefore, no official endorsement should be inferred. Any mention of trade names or commercial products does not constitute endorsement or recommendation for use.

ACKNOWLEDGEMENTS

EPA acknowledges the significant contributions from Ms. Anita Anderson, P.E. of the Minnesota Department of Health. Her efforts included coordinating and managing the field studies at the Safe Water for All Minnesota People (SWAMP) training facility on Fall Lake near Ely, Minnesota. Ms. Anderson also provided an external review and directly contributed to the development of portions of this document.

EPA acknowledges the in-kind support and contributions of Mr. David Pearson with Membrane Systems Specialists, Inc. in Hamilton, OH. Mr. Pearson loaned Fyne Process pilot-units for the microbial removal studies in Ely, Minnesota and in Cincinnati, Ohio and provided an external review of this document.

EPA CONTRIBUTORS

Dr. John Ireland served as Project Officer on EPA Contract No. EP-C-04-034 and Mr. Craig L. Patterson P.E., served as the Work Assignment Manager for this research project.

Mr. Jeffrey Q. Adams and Dr. Jeff Yang, P.E., performed technical reviews of the document.

Mr. John Olszewski and Mr. Stephen M. Harmon were the EPA Quality Assurance Managers, and were responsible for the quality assurance review of the document.

FOREWORD

The U.S. Environmental Protection Agency (EPA) is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory (NRMRL) is the Agency's center for investigation of technological and management approaches for preventing and reducing risks from pollution that threaten human health and the environment. The focus of the Laboratory's research program is on methods and their cost-effectiveness for prevention and control of pollution to air, land, water, and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites, sediments and groundwater; prevention and control of indoor air pollution; and restoration of ecosystems. NRMRL collaborates with both public and private sector partners to foster technologies that reduce the cost of compliance and to anticipate emerging problems. NRMRL's research provides solutions to environmental problems by: developing and promoting technologies that protect and improve the environment; advancing scientific and engineering information to support regulatory and policy decisions; and providing the technical support and information transfer to ensure implementation of environmental regulations and strategies at the national, state, and community levels.

This publication has been produced as part of the Laboratory's strategic long-term research plan. It is published and made available by EPA's Office of Research and Development to assist the user community and to link researchers with their clients.

Sally Gutierrez, Director
National Risk Management Research Laboratory

Notice

This report has been summarized to show only the results that the Seccua Virex Pro units achieved during the tests. No statements as made in the full report have been modified nor been taken out of their overall context. A full report is either available through Seccua (info@seccua.com) or through the EPA website.

The parts of the document, from which text has been removed, are marked with (...).

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1.0 Introduction

The Water Supply and Water Resources Division (WSWRD) of the U. S. EPA's National Risk Management Research Laboratory (NRMRL) has been conducting tests on small drinking water treatment systems since 1997 in response to the 1996 Reauthorization of the Safe Drinking Water Act (SDWA). The SDWA established standards for drinking water systems and required EPA to assess treatment technologies for small systems serving fewer than 10,000 people. Initial tests were focused on packaged bag and cartridge filtration systems. Subsequently, the program has been expanded to test a variety of filtration systems for the removal of turbidity, chemical contaminants, and microbial contaminants. Under contract to EPA, Shaw Environmental, Inc. (Shaw) has been providing technical support in the evaluation of various filtration systems at the EPA T&E Facility in Cincinnati, OH and at a number of field locations.

Color and organic matter are often present in lake water and these constituents are difficult to remove using conventional treatment technologies. The organic matter can also serve as a precursor to the formation of disinfection byproducts (DBPs). This report documents the results of tests conducted on the following four filtration systems for the removal of turbidity, color, organic matter, microorganisms and their surrogates from surface water

(...)

- 1) Virex Pro unit manufactured by Seccua GmbH (Steingaden, Germany) that consists of hollow fiber membranes in a stainless steel housing.

(...)

The tests were conducted at the U.S. Environmental Protection Agency's (EPA's) Test and Evaluation (T&E) Facility in Cincinnati, OH and at a field site in Ely, Minnesota (MN) in collaboration with the Minnesota Department of Health (MDH).

2.0 System Description, Operation and Testing Procedures

This section provides a summary description of the systems evaluated and the associated operation and testing procedures employed at the field site in Ely, MN and at the T&E Facility in Cincinnati, OH. The test procedures employed are presented in the following EPA-endorsed Quality Assurance Project Plans (QAPPs):

- EPA QA ID No. 627-Q-10-0 (Shaw, 2007)
- Amendment 1 to EPA QA ID No. 627-Q-10-0 (Shaw, 2008)
- QA ID No. 627-Q-11-0 (Shaw, 2009)

2.1 Field Test Site

The field test site was located on the grounds of the Outdoor Learning Center just outside the town of Ely, MN. The learning center also houses the Safe Water for All Minnesota People (SWAMP) that includes classroom facilities and a laboratory. Color and turbidity measurements were performed by MDH in this laboratory as a part of this study. The tested units were installed in the test trailer owned and operated by MDH. Shaw contracted with Midwest Water Engineering (MWE) to provide power to the test trailer and install the lake water pump to supply the trailer with test water. MWE also provided services for the installation of the systems and for the construction of a skid that facilitated the testing of the NOK modules. MDH operated the systems to gather data for turbidity removal and color removal. Shaw and EPA conducted a series of tests to evaluate the test systems for the removal of microorganisms.

(...)

2.2 Virex Pro Filtration System

The Virex Pro unit is manufactured by Seccua GmbH in Germany and is a water filtration unit that consists of dual hollow fiber membrane modules with a nominal pore size of 15 nanometers. The system is operated in a dead-end mode without a reject stream. The system can be cleaned at specific intervals, time-of-day or fouling-based frequency. Combinations of forward flushes with backwashes are possible. The cleaning efficiency can be enhanced by the use of chemicals. The system is commercially available in two maximum filtration flow rate capacities – 9.7 gpm and 17.8 gpm. The pilot-scale system was operated between 2.5-3.5 gpm (10 Lpm). Figure 2-8 shows the various features of the system.

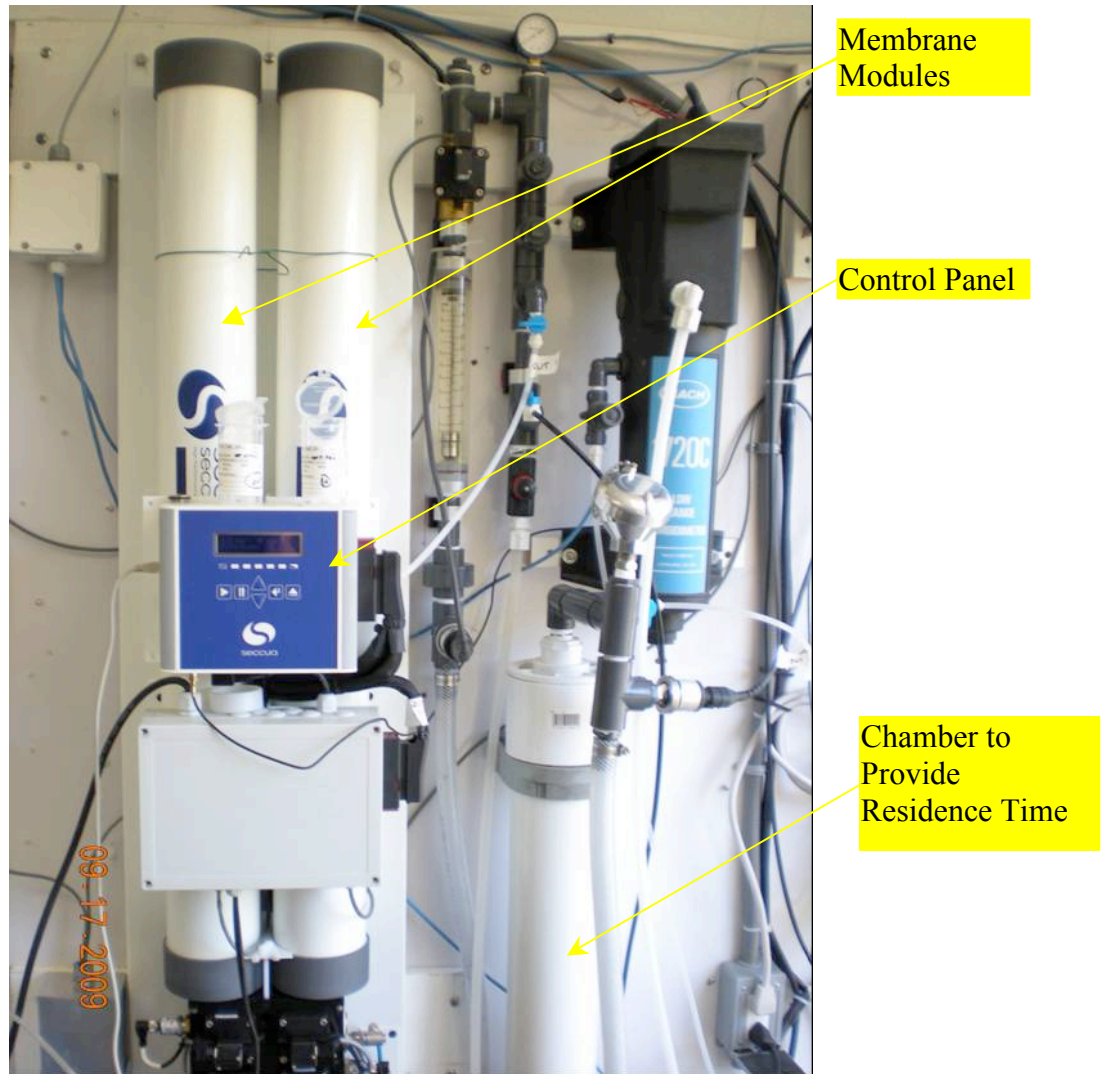


Figure 2-1. Virex Pro Filtration System

2.3 System Operation and Test Conditions

2.3.1 Turbidity, Color and Microbial Challenges

Tests were carried out to evaluate the performance of the different systems in removing turbidity, color, organic matter, bacteria, virus, and protozoa using the following test matrix, organisms or surrogates:

- For turbidity challenges at the field site, the systems were operated using surface water from the lake as the feed source with as-received turbidity levels. Samples were collected for turbidity, TOC, and color during the operation of the system.
- At the T&E Facility, the systems were evaluated for color and TOC removal but not for turbidity removal. For evaluating removal of TOC and color, the systems were challenged using dechlorinated potable water spiked with Bio-hume to achieve a target TOC concentration of 10 mg/L.
- For bacteria removal, the systems were challenged with *Bacillus subtilis* (*B. subtilis*) endospores at the T&E Facility and at the field site. Additionally, the ITT system and the R3f system were tested with *Escherichia coli* (*E. coli*) at the T&E Facility.
- For protozoa removal, the systems were challenged with 3.0 µm Polystyrene Latex (PSL) beads as a surrogate for *Cryptosporidium Parvum* (*C. parvum*). These tests were conducted at the T&E Facility.
- For a preliminary evaluation of virus removal potential, the systems were challenged with MS2 bacteriophage (a surrogate for enteric viruses) at the field site.

For *B. subtilis*, *E. coli*, MS2 bacteriophage and PSL beads, 1 mL of stock suspension with an approximate concentration of 10^9 cells/surrogates per mL was mixed with 500 mL of 0.01% Tween 20 in a 1-L glass beaker. A sub-sample was collected to determine the actual concentration of the injection suspension. The 500 mL suspension and the rinseate were added into the influent stream of the system using a peristaltic pump. The total injection time was approximately 60 minutes. Detailed descriptions of *B. subtilis*, *E. coli* and PSL bead stocks and their suppliers are described in the QAPPs for this project. MS2 bacteriophage stock was obtained from BioVir laboratory (Benicia, CA).

Tests were conducted on the ITT Fyne Technology system in the recycle mode and in the dead-end mode of operation. In the recycle mode, the modules were operated with approximately 20% reject water; there was no reject water during the dead-end mode of operation. The proportion of reject water flow was controlled by a valve. In the tests conducted at Ely, MN

there was no reject stream other than during foam ball cleanings. The reject water valve was closed during the tests conducted in the dead-end mode of operation at the T&E Facility. The GE Pentair and the Virex Pro systems were operated in the dead-end mode only.

2.3.2 Sampling and Analytical Procedures

The sampling and analytical procedures are described in project QAPPs. PSL beads samples (1 L) were collected following a grab sampling method instead of the membrane sampling method because the effluent water pressure was insufficient to allow the water to pass through the collection membrane.

3.0 Test Results

This section summarizes the results of tests conducted on the (...) Virex Pro (...) systems to evaluate the performance in removing different microbiological contaminants, color, organic matter, particle count, and turbidity. Table 3-1 presents a summary of the challenge tests that were conducted on the (...) filtration systems at the T&E Facility and at the MN field site. In addition to the challenge tests, MDH monitored turbidity, color, conductivity, and particle count on an ongoing basis for the systems at the field site.

Table 3.1. Summary of Challenge Tests Conducted on Different Systems

| Date | Test ID | Membrane Configuration | Mode of Operation |
|--|---------------------------|------------------------|-------------------|
| (...) | | | |
| Field Test 2009: ITT Fyne 3-Foot Module and Virex Pro Systems | | | |
| 9/15/09 | <i>B. subtilis</i> Test 1 | Virex Pro | Dead-end |
| 9/16/09 | <i>B. subtilis</i> Test 3 | Virex Pro | Dead-end |
| 9/15/09 | MS2 bacteriophage Test 1 | Virex Pro | Dead-end |

3.1 *B. subtilis* Field Test Results

(...)

The following test runs were conducted on the (...) Virex Pro system in 2009 to evaluate the removal of *B. subtilis*:

Test 1 – Virex Pro System in Dead-End Mode

(...)

Test 3 – Virex Pro System in Dead-End Mode (Replicate of Test 1)

(...)

The test results are organized by system in the following sections. The performance of a system at a particular sampling event was evaluated by comparing the influent and effluent concentrations of the contaminant and calculating an average log removal value was determined comparing the average influent and effluent concentrations of the contaminant during a particular test.

(...)

3.1.1 *B. subtilis* Tests Results for the Virex Pro System

Table 3-5 presents the *B. subtilis* analytical results for two tests conducted on the Virex Pro system at Ely, MN in 2009. For these tests, the *B. subtilis* injection was completed at T30 and injection of the chaser solution injection completed at T60. The Virex Pro system achieved complete removal (> 4.7 log) of *B. subtilis* in two tests conducted in the dead-end mode of operation.

Table 3.2. *B. subtilis* Analytical Results for Virex Pro System at Ely, MN in September 2009

| Sampling Time (min) | No. Cells/100 ml | | Log Removal | Average Log Removal |
|------------------------------|-------------------|-----|-------------|---------------------|
| | IN | Out | | |
| Test 1: Dead-End Mode | | | | |
| T0 ^a | 0 | 0 | - | CR (> 4.7) |
| T5 | N/A ^b | 0 | - | |
| T15 | 4.0×10^4 | 0 | CR (> 4.6) | |
| T15 Dup | 4.0×10^4 | 0 | CR (> 4.6) | |
| T30 | 8.0×10^4 | 0 | CR (> 4.9) | |
| T60 ^a | 1.6×10^3 | 0 | CR (> 3.2) | |
| Test 3: Dead-End Mode | | | | |
| T0 ^a | 0 | 0 | - | CR (> 4.6) |
| T5 | 7.5×10^4 | 0 | - | |
| T15 | 8.5×10^4 | 0 | CR (> 4.9) | |
| T15 Dup | 7.0×10^4 | 0 | CR (> 4.8) | |
| T30 | 1.2×10^5 | 0 | CR (> 5.1) | |
| T60 | 2.2×10^4 | 0 | CR (> 4.3) | |

^a Data not considered for performance evaluation due to low influent concentration; ^b Not Available, sample was overdiluted
 CR – Complete Removal, log removal value was based on the influent concentration.

3.2 MS2 bacteriophage Field Test Results

The following test runs were conducted on the 3-foot ITT Fyne Technology system and the Virex Pro system at the field site in September 2009 to evaluate the removal of MS2 bacteriophage:

- Test 1 – Virex Pro System in Dead-End Mode
- (...)

3.2.1 MS2 bacteriophage Results for Virex Pro System

Table 3-6 presents the MS2 bacteriophage analytical results for the single test conducted on the Virex Pro system at Ely, MN in September 2009. For this test, the MS2 bacteriophage injection was completed at T30 and injection of the chaser solution injection completed at T60. Complete removal (> 4.7 log) of MS2 bacteriophage was achieved by the Virex Pro system in the single test conducted in the dead-end mode of operation.

Table 3.3. MS2 bacteriophage Analytical Results for Virex Pro System at Ely, MN in September 2009

| Sampling Time (min) | No. Cells/100 ml | | Log Removal | Average Log Removal |
|---------------------|-------------------|-----|-------------|---------------------|
| | IN | Out | | |
| T0 | N/A ^b | 0 | - | CR (> 4.7) |
| T5 | 5.0×10^4 | 0 | CR (> 4.7) | |
| T15 | 5.0×10^4 | 0 | CR (> 4.7) | |
| T15 Dup | 6.0×10^4 | 0 | CR (> 4.8) | |
| T30 | 2.0×10^4 | 0 | CR (> 4.3) | |
| T60 ^a | 6.2×10^3 | 0 | CR (> 3.8) | |

^a Data not considered for performance evaluation due to low influent concentration; ^b Not Available, sample was underdiluted
 CR – Complete Removal, log removal value was based on the influent concentration

(...)

3.3 Raw Water and Backwash Samples

To confirm that there were negligible *B. subtilis* spores in the lake water, an untreated lake water sample was analyzed. The results of analysis on two lake water samples (Sample 1 – 0 cells/mL; Sample 2 – 0.2 cells/mL) confirmed that there was negligible *B. subtilis* in the lake water.

A sample was also collected from the GE Pentair System backflush water. The *B. subtilis* count in this sample could not be quantified because they were too many to count (TMTC).

4.0 Conclusions

The (...) Virex Pro system demonstrated complete removal (> 4.7 log) of *B. subtilis* during the tests conducted at field location. When tested with MS2 bacteriophage, the Virex Pro system demonstrated complete removal (> 4.7 log) at field location. The Virex Pro system demonstrated good removal of turbidity (approximately 87%) and moderate removal (approximately 54%) of color.

5.0 References

Shaw. “Quality Assurance Project Plan for Membrane-based Small System Technologies for the Treatment of Bacteria and Reduction of Color in Surface Waters”, EPA QA ID: 627-Q-11-0, 2009

Shaw. “Addendum to Quality Assurance Project Plan for Glass Bead R3f and Multimedia Systems”, EPA QA ID: 627-Q-10-1, 2008

Shaw. “Quality Assurance Project Plan for Glass Bead R3f and Multimedia Systems”, EPA QA ID: 627-Q-10-0, 2007