THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM

U.S. Environmental Protection Agency

NSF International

ETV Joint Verification Statement

TECHNOLOGY TYPE:	**ULTRAFILTRATION MEMBRANE**
APPLICATION:	**REMOVAL OF VIRUSES IN DRINKING WATER**
PRODUCT NAME:	**SFD-2880 ULTRAFILTRATION MODULE**
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NSF International (NSF) manages the Drinking Water Systems (DWS) Center under the U.S. Environmental Protection Agency's (EPA) Environmental Technology Verification (ETV) Program. The DWS Center recently evaluated the performance of the Dow Water Solutions SFD-2880 ultrafiltration (UF) module for removal of viruses under a scenario where one UF fiber was broken. The challenge test was conducted under controlled laboratory conditions at NSF's testing laboratory in Ann Arbor, MI. Testing of the SFD-2880 UF module was conducted to verify virus reduction following the requirements of the Department of Health Victoria (Australia) *Draft guidelines for validating treatment processes for pathogen reduction, supporting Class A water recycling schemes in Victoria*. The Department of Health Victoria guideline is largely based on the product-specific challenge requirements of the EPA Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR) and accompanying EPA Membrane Filtration Guidance Manual (MFGM).

EPA created the ETV Program to facilitate the deployment of innovative or improved environmental technologies through performance verification and dissemination of information. The goal of the ETV Program is to further environmental protection by accelerating the acceptance and use of improved and more cost-effective technologies. ETV seeks to achieve this goal by providing high-quality, peer-reviewed data on technology performance to those involved in the design, distribution, permitting, purchase, and use of environmental technologies.

ETV works in partnership with recognized standards and testing organizations, stakeholder groups (consisting of buyers, vendor organizations, and permitters), and with the full participation of individual technology developers. The program evaluates the performance of innovative technologies by developing test plans that are responsive to the needs of stakeholders, conducting field or laboratory tests (as appropriate), collecting and analyzing data, and preparing peer-reviewed reports. All evaluations are conducted in accordance with rigorous quality assurance protocols to ensure that data of known and adequate quality are generated and that the results are defensible.

ABSTRACT

The purpose of this verification was a cut fiber challenge study for the Dow Chemical Company SFD-2880 UF membrane module. MS2 coliphage virus was the surrogate challenge organism. The challenge tests followed the requirements of the Department of Health Victoria (Australia) *Draft guidelines for validating treatment processes for pathogen reduction, supporting Class A water recycling schemes in Victoria*.

Five new fully integral modules were challenged with MS2. Then, one fiber in each module was cut, and the modules were all tested again with MS2. The modules were operated at a target flux of 70 gallons per square foot per day (gfd), which equates to a flow of 40.3 gallons per minute (gpm). The test data did not show any significant reduction in virus removal with a cut-fiber, so a second round of testing was conducted with higher MS2 challenge concentrations. For the retests, the cut-fiber challenges were conducted first, followed by the intact module tests after the cut fibers were pinned. The average log removal value (LRV) was calculated for each module, as well as LRVs for each feed/filtrate sample pair. From this data, the $LRV_{C\text{-}TEST}$ was determined as the lowest mean LRV, and also the lowest sample pair LRV. Table VS-i provides a summary of the $LRV_{C\text{-}TEST}$ data.

Table VS-i. $LRV_{C\text{-}TEST}$ for Each Round of Testing

	Intact Modules		Cut Fiber	
Tests	**Mean LRV**	**Lowest LRV**	**Mean LRV**	**Lowest LRV**
Round 1	3.73	3.44	3.44	2.98
Round 2	2.59	2.39	2.46	2.37

To evaluate whether there was significantly lower virus removal with a cut fiber, the LRVs for each feed/filtrate sample pair were pooled together, and the paired-difference t statistic was calculated using Microsoft® Excel®. The intact module vs. cut-fiber t statistic for the first round of tests is 1.15. This value is below the critical t value of 2.15, indicating that virus removal was not significantly impacted by the cut fiber. For the second round of tests, the paired-difference t statistic is 5.00, this time demonstrating a statistically significant drop in LRV.

PRODUCT DESCRIPTION

The following information was provided by Dow and was not verified.

The Dow SFD-2880 UF membrane module measures 4.7 inches in diameter by 45.5 inches in length. The membrane fibers are made of polyvinylidene fluoride (PVDF). Water flow through the membrane fibers is outside to inside. The modules can operate in deposition (dead-end) or suspension modes. The nominal pore size is 0.03 µm. The maximum recommended flux is 70 gfd, with a maximum recommended feed pressure of 44 pounds per square inch (psi), and a maximum transmembrane pressure of 30 psi.

VERIFICATION TEST DESCRIPTION

Virus Surrogate

The modules were challenged with the MS2 coliphage virus (ATCC 15597-Bl) as a surrogate for enteric viruses, as required by the Victoria draft guidelines for virus removal credits. MS2 is generally accepted as an enteric virus surrogate for size-exclusion technologies due to its small size (approximately 22-26 nanometers). The USEPA MFGM references MS2 as an acceptable surrogate for enteric viruses because it is similar in size and shape to poliovirus and hepatitis virus.

Methods and Procedures

All tests were conducted at the NSF International testing laboratories following the requirements of the EPA-approved *Test/QA Plan for Validating the Dow Chemical Company SFD-2880 Ultrafiltration Membrane Module for Virus Reduction Following the Department of Health Victoria (Australia) Draft Guidelines for Validating Treatment Processes for Pathogen Reduction.* The Victoria guidelines support the regulatory approval process for Class A water recycling schemes. For membrane filtration products, the guidelines are largely based on the product-specific challenge requirements of the LT2ESWTR and accompanying EPA MFGM.

The intact module and cut-fiber tests were conducted twice, in two separate rounds of testing. The second round of testing was conducted because the data from the first round did not show any significant reduction in virus retention between the intact and cut-fiber challenges. For the first round, NSF tested the five intact modules in January 2011. Then Dow representatives visited the testing laboratory to cut the fibers, and the cut-fiber tests were conducted in March 2011. As required in the Department of Health Victoria guideline, one fiber in each module was cut as close as possible to the potting resin on the filtrate end of the module. The retests were conducted in May 2011, with the cut-fiber tests conducted first, followed by the intact module challenges after Dow representatives pinned the cut fibers. Each of the five modules submitted for testing was challenged individually. The target flux for membrane operation was Dow's maximum recommended value of 70 gfd at 25 °C, which equals a flow rate of 40.3 gpm. Before and after each challenge test, each module was subjected to a pressure decay test to satisfy the non-destructive performance test requirement in Section 3.6 of the MFGM.

Immediately prior to testing, each module was forward flushed at approximately 40 gpm. For the first round of tests conducted in January and March, each module was flushed for five minutes. At the start of the retest round in May, the laboratory engineer noticed that after five minutes of flushing, there were still bubbles visible in the filtrate hose line. The engineer flushed Module 1 for an additional three minutes until bubbles were no longer visible. The engineer had to flush Module 2 for a total of 22 minutes to clear the bubbles. At this point, the engineer decided to install bleed valves in the reject port caps for Modules 3, 4 and 5 to allow for evacuation of the air. After the pressure decay tests for these three modules, the bleed valve was opened and the flow of water started at 40 gpm. The valves were kept open until all the air had escaped. This allowed the testing engineer to return to the flush time of five minutes.

The duration of each challenge test was approximately 35 minutes. The MS2 suspension was injected into the feed stream at start-up, after 15 minutes of operation, and after 30 minutes of operation. After at least one minute of injection to pass the equilibrium volume, grab samples were collected from the feed and filtrate sample taps. After each round of sample collection, injection of the challenge organism suspension was turned off, and clean feed water was pumped through the modules at 40 gpm until the next sampling point.

VERIFICATION OF PERFORMANCE

The LT2ESWTR and MFGM specify that an LRV for the test ($LRV_{C\text{-}TEST}$) be calculated for each module tested, and that the LRVs for each module are then combined to yield a single $LRV_{C\text{-}TEST}$ for the product.

If fewer than 20 modules are tested, as was the case for this verification, the $LRV_{C\text{-}TEST}$ is simply the lowest LRV for the individual modules. However, the rule does not specify a method to calculate $LRV_{C\text{-}TEST}$ for each module. Suggested options in the MFGM include:

- Calculate a LRV for each feed/filtrate sample pair, then calculate the average of the individual sample point LRVs;
- Average all of the feed and filtrate counts, then calculate a single LRV for the module; or
- Calculate a LRV for each feed/filtrate sample pair, select the LRV for the module as the lowest (most conservative of the three options).

Options 1 and 2 give $LRV_{C\text{-}TEST}$ values that are either identical, or only a few hundredths or less different, so for this verification, options 1 and 3 are used to calculate LRVs.

First Round Results

The MS2 LRVs for the first round of tests are presented in Table VS-ii. The intact module $LRV_{C\text{-}TEST}$, using the overall mean LRV calculations in Table VS-ii, is 3.73. The $LRV_{C\text{-}TEST}$ based on the lowest individual sample pair log reduction is 3.44. Under the cut-fiber scenario, the $LRV_{C\text{-}TEST}$ from the overall means is 3.44, while that from the lowest individual sample pair log reduction is 2.98.

Table VS-ii. First Round LRV Calculations

	Intact Modules		Cut Fiber	
Module #	**Mean LRV**	**Lowest LRV**	**Mean LRV**	**Lowest LRV**
Module 1	3.92	3.85	3.44	3.10
Module 2	3.73	3.44	3.72	2.98
Module 3	4.55	4.09	4.73	4.19
Module 4	3.82	3.65	4.93	4.65
Module 5	4.17	3.90	4.49	4.30

To evaluate whether there was significantly lower virus removal with a cut fiber, the LRVs for the feed/filtrate sample pairs were pooled together, and the paired-difference t statistic was calculated using Microsoft® Excel®. The mean LRV for all five intact modules is 4.04, with individual sample pair LRVs ranging from 3.44 to 5.16. The mean LRV for the cut-fiber tests is actually higher, at 4.26, with a range of 2.98 to 5.74. The paired-difference t statistic for the two sets of LRVs is 1.15, which is below the critical t value of 2.15 (14 degrees of freedom) that denotes a significant difference with a confidence of 95%.

The intact module pressure decay rates ranged from 0.000 to 0.052 psi/min, while those for the cut-fiber scenario ranged from 0.734 to 1.292 psi/min, indicating that there was indeed a significant integrity breach.

A possible explanation for why there was no significant difference between the intact module and cut-fiber scenarios arises from the testing engineer's observation of air bubbles in the filtrate during the pre-test flushes for the retests, as discussed above. If a portion of the air introduced for the pressure decay test was still trapped at the top of the module during the challenge test, the cut fiber at the top of the module may have never been in contact with the challenge water during the first round of tests; it may have been in a pocket of air trapped at the top of the module. This theory is bolstered by a comparison of the feed pressure data for the first round of tests versus the retests. For the first round of tests, above 20 psi driving pressure was needed for eight of the ten test runs to achieve the target flux, compared with less than 18 psi for the retests. If air was trapped in the modules, thus occluding a significant portion of the membrane surface area, a higher driving pressure would be needed to achieve the target flux, due to the smaller surface area.

To attempt to discern a significant difference in LRV between the intact modules and modules with a cut fiber, NSF and Dow decided to re-run the tests on the same five modules using a higher MS2 challenge.

Second Round Results

The LRVs for the second round of tests are displayed in Table VS-iii. The intact module $LRV_{C\text{-}TEST}$, using the overall mean LRV calculations in Table VS-iii, is 2.59. The $LRV_{C\text{-}TEST}$ based on the lowest individual sample pair log reductions is 2.39. Under the cut-fiber scenario, the $LRV_{C\text{-}TEST}$ from the overall means is 2.46, while that from the lowest individual sample pair log reductions is 2.37. The intact module pressure decay rates ranged from 0.000 to 0.035 psi/min, while those for the cut-fiber tests ranged from 0.970 to 1.284 psi/min.

Table VS-iii. Second Round LRV Calculations

	Intact Modules		**Cut Fiber**	
Module #	**Mean LRV**	**Lowest LRV**	**Mean LRV**	**Lowest LRV**
Module 1	3.39	3.23	3.13	3.12
Module 2	3.10	2.90	2.67	2.66
Module 3	3.36	3.09	2.93	2.87
Module 4	3.27	3.04	2.77	2.53
Module 5	2.59	2.39	2.46	2.37

In contrast to the first round LRV data, the retest data set does show a statistically significant difference in virus retention between the intact and cut-fiber scenarios. The mean LRV for all five intact modules is 3.14, with a range of 2.39 to 3.62. The mean LRV for the cut-fiber tests is 2.79, with a range of 2.37 to 3.14. The paired-difference t statistic for the two sets of LRV's is 5.00, which is above the critical t value of 2.15 for a significant difference at the 95% confidence level.

The pressure decay rates indicated a catastrophic loss of membrane integrity, but the corresponding loss of virus retention was not as large. For the retests, the cut-fiber pressure decay rates were approximately 30 times higher than those for the intact modules. This translates into an approximate 1.5 log loss of membrane integrity. However, the MS2 reduction data only shows a mean LRV loss of 0.35 logs.

QUALITY ASSURANCE/QUALITY CONTROL (QA/QC)

NSF provided technical and quality assurance oversight of the verification testing as described in the verification report, including a review of 100% of the data. NSF QA personnel also conducted a technical systems audit during testing to ensure the testing was in compliance with the test plan. A complete description of the QA/QC procedures is provided in the verification report.

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Availability of Supporting Documents
Copies of the test protocol, the verification statement, and the verification report (NSF report # NSF 12/35/EPADWCTR) are available from the following sources:

1. ETV Drinking Water Systems Center Manager (order hard copy)
   NSF International
   P.O. Box 130140
   Ann Arbor, Michigan 48113-0140

2. Electronic PDF copy
   NSF web site: http://www.nsf.org/info/etv
   EPA web site: http://www.epa.gov/etv