THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM

U.S. Environmental Protection Agency

NSF International

ETV Joint Verification Statement

TECHNOLOGY TYPE:	**ULTRAFILTRATION**
APPLICATION:	**REMOVAL OF MICROBIAL CONTAMINANTS**
PRODUCT NAME:	**SFD-2880 ULTRAFILTRATION MODULE**
VENDOR:	**THE DOW CHEMICAL COMPANY – DOW WATER SOLUTIONS**
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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 microbial contaminants under controlled laboratory challenge conditions. The challenge tests were conducted at NSF's testing laboratory in Ann Arbor, MI. Testing of the SFD-2880 UF module was conducted to verify microbial reduction performance under the product-specific challenge requirements of the USEPA Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR).

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 Dow SFD-2880 UF module was tested for removal of microorganisms using live *Cryptosporidium parvum* oocysts, endospores of the bacteria *Bacillus atrophaeus*, and the MS2 coliphage virus according to the product-specific challenge testing requirements of the EPA Long-Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR). Six modules were challenged with *B. atrophaeus* endospores and MS2. Separate challenges were conducted for each organism. The *B.* atrophaeus endospores served as a surrogate for *Cryptosporidium*. Two of the six modules were challenged with *C. parvum* oocysts to experimentally confirm the surrogate relationship. 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 LT2ESWTR specifies that log removal values (LRV) be calculated for each module for each organism, and then one LRV for each organism ($LRV_{C\text{-}TEST}$) be assigned from the set of LRVs. However, the rule does not specify how the $LRV_{C\text{-}TEST}$ should be determined, instead, different methods are suggested. For this verification, LRVs were calculated for each feed/filtrate sample pair, and an average LRV was calculated for each module. For each challenge organism two $LRV_{C\text{-}TEST}$ are reported. The first is the lowest average LRV from each challenge test. The second is the lowest individual sample point LRV across all of the modules tested.

The $LRV_{C\text{-}TEST}$ results for each organism by each method are displayed below in Table VS-i.

Table VS-i. $LRV_{C\text{-}TEST}$ for Each Organism

Challenge Organism	Mean LRV	Lowest LRV
C. parvum	6.20	5.97
B. atrophaeus	5.90	5.77
MS2	2.54	2.37

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.

For this verification, the modules were operated in dead-end mode at the maximum recommended flux of 70 gfd, unless otherwise indicated.

VERIFICATION TEST DESCRIPTION

Challenge Organisms

The SFD-2880 module was tested for removal of microorganisms using live *C. parvum* oocysts, endospores of the bacteria *B. atrophaeus* (ATCC 9372, deposited as *Bacillus subtilis* var. *niger*), and MS2 coliphage virus (ATCC 15597-Bl). *B. atrophaeus* served as surrogate for *C. parvum*, due to the high cost and lack of availability of the amount of *C. parvum* required to test six modules. Virus reduction was evaluated using MS2 for possible virus removal credits. MS2 is considered a suitable surrogate for pathogenic viruses because of its small size of approximately 24 nanometers in diameter.

Methods and Procedures

All tests were conducted at the NSF International testing laboratories. The tests followed the procedures described in the *Test/QA Plan for the Microbial Seeding Challenge Study of the Dow Chemical Company SFD-2880 Ultrafiltration Module.* The challenge protocol was adapted from the *ETV Protocol for Equipment Verification Testing for Physical Removal of Microbiological and Particulate Contaminants*, and the USEPA *Membrane Filtration Guidance Manual* (MFGM), and met the product-specific challenge test requirements of the LT2ESWTR.

Each of the SFD-2880 modules submitted for testing was challenged individually, and separate challenge tests were conducted for each organism. 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. A total of six modules were submitted for testing. The test plan called for testing only five modules, but the module tested for *Cryptosporidium parvum* reduction developed an apparent membrane breach during the test. As a result, Dow chose to submit a sixth module for testing so they could have a five-module data set demonstrating the performance of fully integral modules.

The LT2ESWTR calls for the maximum challenge concentration to be 6.5 $\log_{10}$ above the organism's detection limit (3.16×10^6). The goal for the *B. atrophaeus* challenges was to be able to measure log reductions greater than six, so NSF elected to target 1×10^7 CFU/100 mL to account for less than 100% recovery of spiked challenge organism concentration. After all six modules were tested, and the feed concentrations were found to be above 6.5 $\log_{10}$, NSF learned that the maximum 6.5 $\log_{10}$ challenge level is not just guidance, but rather the maximum allowed in the rule language in the Federal Register. Therefore, NSF decided to retest two modules with lower challenge levels to provide a data set that meets rule requirements. NSF also learned from EPA that the States could accept data from high feed challenge tests, provided that feed concentrations were capped at 6.5 $\log_{10}$ for the purpose of calculating the LRV. Therefore, two sets of LRV calculations are presented here and in the full verification report, one set using the measured feed counts, and a second set with the feed concentration set at 6.5 $\log_{10}$.

The duration of each challenge test was approximately 35 minutes. The challenge organisms were 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, 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.

After the MS2 reduction data was shared with Dow, they requested that NSF conduct three more MS2 reduction challenges on one module at lower fluxes to identify whether MS2 reduction would increase as the flux was lowered, and to generate a curve of MS2 reduction vs. flux. The procedure for these tests was the same as for the previous tests. Module 5 was randomly chosen for testing by the laboratory testing engineer. The tests were conducted at the target flows of 13.6 gpm, 25.4 gpm, and 35.6 gpm. These flow rates translate into fluxes of 23.6, 44.1, and 61.8 gfd, respectively.

VERIFICATION OF PERFORMANCE

The feed and filtrate challenge organism triplicate counts were averaged by calculating geometric means. Geometric means <1 were rounded up to 1, unless all three triplicate analyses had no organisms found. The mean counts were then $\log_{10}$ transformed to calculate log removal values (LRV).

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.

Each module was challenged with both *B. atrophaeus* and MS-2 on the same day. After all of the modules were tested, the *B. atrophaeus* data was examined to choose the module to undergo the *C. parvum* challenge test. Modules 2 and 3 were the only ones with *B. atropheaus* CFU found in all three triplicate counts of a filtrate sample. For Module 2, 1 CFU was found in each of the triplicate measurements for the 2-minute filtrate sample. For Module 3, the 30-minute filtrate sample triplicate counts were 3, 1, and 1 CFU, so Module 3 was chosen over Module 2 for the *C.* parvum test. During the *C. parvum* test, there was a possible integrity breach that developed, because the post-test pressure decay rate was approximately double that measured immediately before the challenge test. When the filtrate samples were analyzed, one *C. parvum* oocyst was found in one of the triplicate analyses for the 30-minute filtrate sample. As a result, Dow decided to submit a sixth module for testing. This sixth module was first challenged with *B. atrophaeus* to compare its performance to the other modules. The *B. atrophaeus* data set was re-examined, omitting Module 3, and Module 2 was chosen for a second *C. parvum* challenge test.

Except for the Module 3 post-*C. parvum* challenge pressure decay rate, the maximum observed pressure decay rate was 0.063 psig/min, indicating there were no other membrane integrity issues during testing.

C. parvum Reduction

The *C. parvum* feed concentrations ranged from $9.4x10^5$ to $2.4x10^6$ oocysts/L for the two tests. As discussed above, because one oocyst was found in a filtrate sample for the Module 3 test and the post-test pressure decay rate indicated a possible membrane breach, Module 2 was also tested for *C. parvum* reduction. The *C. parvum* LRVs from the two different calculation methods are presented in Table VS-i. All $\log_{10}$ transformations of the filtrate samples are zero, so the LRVs are simply a function of the measured feed concentrations. The $LRV_{C\text{-}TEST}$ from the overall means is 6.20, while the $LRV_{C\text{-}TEST}$ from the individual sample pairs is 5.97. The flows recorded during the *C. parvum* challenges translate into fluxes ranging from 69.7 to 70.0 gfd.

Table VS-i. *C. parvum* LRV Calculations

Module #	Mean LRV	Lowest LRV
Module 3	6.20	5.97
Module 2	6.26	6.18

B. atrophaeus Reduction

The *B. atrophaeus* feed concentrations for the tests ranged from $7.3x10^6$ to $1.63x10^7$ CFU/100 mL for the first round of tests. As discussed above, because the challenge concentrations were above the allowable maximum of 6.5 $\log_{10}$, two modules were retested with lower challenge concentrations. The feeds for the retests ranged from $9.4x10^5$ to $1.29x10^6$ CFU/100 mL.

The *B. atrophaeus* LRVs are displayed in Table VS-ii. Where the feed concentrations are above 6.5 $\log_{10}$, two LRVs are listed, one based on the measured feed concentration, and a second based on the feed capped at 6.5 $\log_{10}$. Considering only the capped feed LRVs from the first round of tests, the $LRV_{C\text{-}TEST}$ from the means is 6.40, and the $LRV_{C\text{-}TEST}$ from the individual sample pairs is 6.20. Including the lower feed concentration retest data, the $LRV_{C\text{-}TEST}$ from the mean individual LRVs is 5.89, and 5.77 from the individual sample pairs. The flows recorded during the *B. atrophaeus* tests translated into fluxes ranging from 69.5 to 70.9 gfd.

Table VS-ii. *B. atrophaeus* LRV Calculations

	LRV Using Measured Feeds		LRV from Capped Feeds	
Module #	**Mean LRV**	**Lowest LRV**	**Mean LRV**	**Lowest LRV**
Module 1	7.05	7.04	6.50	6.50
Module 2	7.10	7.08	6.50	6.50
Module 3	7.05	7.00	6.50	6.50
Module 4	6.87	6.70	6.40	6.20
Module 5	7.12	7.09	6.50	6.50
Module 6	7.18	7.11	6.50	6.50
Module 2 Retest	5.98	5.97	NA	NA
Module 4 Retest	5.89	5.77	NA	NA

MS2 Reduction

The MS2 feed concentrations ranged from $7.6x10^5$ PFU/mL to $3.4x10^6$ PFU/mL for Modules 1 through 5, while the feeds for the Module 6 test were just above $1x10^7$ PFU/mL. Therefore, the feed concentrations for Module 6 were capped at 6.5 $\log_{10}$. The LRVs for the MS2 reduction tests are displayed in Table VS-iii. The $LRV_{C\text{-}TEST}$ based on the mean LRVs is 2.54, and that based on the lowest individual sample pair LRVs is 2.37. The flows recorded during the MS2 challenges translated into fluxes ranging from 69.5 to 71.9 gfd.

Table VS-iii. MS2 LRV Calculations

Module #	**Mean LRV**	**Lowest LRV**
Module 1	4.52	4.47
Module 2	3.75	3.60
Module 3	3.48	3.37
Module 4	3.34	3.08
Module 5	3.24	2.99
Module 6	2.54	2.37

MS2 Reduction vs. Flux

Dow requested that NSF conduct three additional MS2 challenge tests at lower flows to determine whether MS2 reduction increased as the flux decreased. Module #5 was chosen for these tests because it was the worst performing module of the five that had been tested.

The LRV calculations for these tests are displayed in Table VS-iv. The data indicates that MS2 reduction is inversely proportional to the flux, but the observed LRVs for the lower flow rate tests are all within the range of LRVs from the maximum flux tests, except for the first sampling point from the 13.6 gpm test. The feed concentrations for these challenges are not capped at 6.5 $\log_{10}$ because the intent of this study was not to provide regulatory compliance data, but rather to supply comparative data on membrane performance at lower fluxes.

Table VS-iv. MS2 LRV at Lower Flows		
Flow	**Mean LRV**	**Lowest LRV**
13.6 gpm	4.28	3.91
25.4 gpm	3.35	3.55
35.6 gpm	2.78	3.16

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 10/34/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