THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM

U.S. Environmental Protection Agency

NSF International

ETV Joint Verification Statement

TECHNOLOGY TYPE:	**POINT-OF-ENTRY DRINKING WATER TREATMENT SYSTEM**
APPLICATION:	**REMOVAL OF CHEMICAL AND MICROBIAL CONTAMINANTS IN DRINKING WATER**
PRODUCT NAME:	**M-2400 REVERSE OSMOSIS SYSTEM**
VENDOR:	**WATTS PREMIER, INC.**
ADDRESS:	**1725 WEST WILLIAMS DRIVE, SUITE C-20 PHOENIX, AZ 85027**
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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 Watts Premier, Inc. M-2400 Point-of-Entry (POE) Reverse Osmosis (RO) Drinking Water Treatment System. NSF performed all of the testing activities and also authored the verification report and this verification statement. The verification report contains a comprehensive description of the testing activities.

The 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 Watts Premier M-2400 POE RO Drinking Water Treatment System was tested at the NSF Drinking Water Treatment Systems Laboratory for removal of the viruses fr and MS2, the bacteria *Brevundimonas diminuta*, and chemicals aldicarb, benzene, cadmium, carbofuran, cesium, chloroform, dichlorvos, mercury, methomyl, mevinphos, oxamyl, paraquat, sodium fluoroacetate, strontium, and strychnine. The microorganisms used in this study served as surrogates for pathogenic bacteria and viruses that may be introduced into drinking water through accidental or intentional contamination. The target chemical challenge concentration was 1 milligram per liter (mg/L). The target microorganism challenge concentrations were $1x10^6$ colony forming units per 100 milliliters (CFU/100 mL) for *B. diminuta*, and $1x10^4$ plaque forming units per milliliter (PFU/mL) for the viruses. NSF also separately tested an optional post-membrane activated carbon filter that Watts Premier offers, the Flowmatic MAXVOC FF-975. This filter was only tested with the chemicals not removed to 20 micrograms per liter (μg/L) or lower by the RO membrane. One M-2400 system and one MAXVOC FF-975 carbon filter were tested. Each challenge was 30 minutes in length. The M-2400 removed a minimum of 2.9 $\log_{10}$ of the viruses, and 2.5 $\log_{10}$ of *B. diminuta*. The M-2400 removed all of the chemicals by 96% or more, except for mercury, which was only removed by 38%. Based on the M-2400 chemical challenge results, the MAXVOC FF-975 filter was challenged with chloroform, dichlorvos, mercury, and methomyl. The MAXVOC FF-975 removed 96% or more of the four chemicals. The M-2400 and MAXVOC FF-975 together removed 99% or more of all chemicals but sodium flouroacetate, whose percent reduction was limited by its high detection limit of 20 μg/L.

TECHNOLOGY DESCRIPTION

The following technology description was provided by the manufacturer and has not been verified.

The M-2400 is a skid-mounted RO system that utilizes one 4" x 40" RO membrane with a surface area of 82 square feet (ft^2). The membrane is fed by a 330 gallons-per-hour booster pump. The system also includes a pre-membrane sediment or activated carbon filter, an optional post-membrane activated carbon filter, and an optional product water storage tank. The M-2400 has a control panel with pressure gauges and flow meters to calibrate the system and monitor performance. The skid measures 27" wide, 32" deep, and 57" high. The system as tested did not include any pre-membrane filters or a storage tank, but did include a post-membrane carbon filter. Watts Premier uses the Flowmatic MAXVOC-FF975 activated carbon filter as an optional post-membrane treatment step for organic chemical removal. The MAXVOC FF-975 is a 4.625" x 9.75" block filter with a rated service flow rate of 2 gallons per minute (gpm).

Under normal operation, raw water entering the system first passes through the sediment or carbon pre-filter to remove large particles. The pre-membrane filter effluent is then sent through the booster pump and then on to the RO membrane. Water passing through the membrane is collected in a permeate line that can be plumbed to a storage tank. A portion of the concentrate water from the membrane module can be recycled back into the feed water line depending on the desired recovery for the system. The remainder of the concentrate is sent to the drain. The recycle rate can be manually adjusted with a needle control valve.

VERIFICATION TESTING DESCRIPTION

Test Site

The testing site was the Drinking Water Treatment Systems Laboratory at NSF in Ann Arbor, Michigan. A description of the test apparatus can be found in the verification report. The testing was conducted in January through April of 2006.

Methods and Procedures

The testing methods and procedures are detailed in the *Test/QA Plan for Verification Testing of the Watts Premier M-2400 Point-of-Entry Reverse Osmosis Drinking Water Treatment System for Removal of Microbial and Chemical Contaminants*. One M-2400 system and one MAXVOC FF-975 filter were tested separately. The M-2400 was challenged with the chemicals, bacteria, and viruses listed in Table VS-1. The MAXVOC filter was only challenged with the chemicals that the RO membrane did not remove to 20 μg/L or below.

The challenge chemicals were chosen from a list of chemicals of interest supplied by the EPA. The challenge bacteria and viruses were recommended by an advisory panel because they are smaller than most other viruses and bacteria, and so provide a conservative estimate of performance. In addition to using *B. diminuta* strain 19146 as obtained from American Type Culture Collection (ATCC), NSF also used a genetically engineered strain of the organism. The NSF Microbiology Laboratory inserted into a culture of *B. diminuta* a gene conferring resistance to the antibiotic kanamycin (KanR *B. diminuta*). This allowed the Microbiology Laboratory to use a growth media amended with 50 μg/L of kanamycin to prohibit heterotrophic plate count (HPC) bacteria in the treated water samples from growing along with the kanamycin resistant *B. diminuta*.

Table VS-1. Challenge Chemicals and Microorganisms

Chemicals	Bacteria	Viruses
Aldicarb	*Brevundimonas diminuta*	fr
Benzene		MS2
Cadmium Chloride		
Carbofuran		
Cesium Chloride (nonradioactive isotope)		
Chloroform		
Dichlorvos		
Mercuric Chloride		
Methomyl		
Mevinphos		
Oxamyl		
Paraquat		
Sodium Fluoroacetate		
Strontium Chloride (nonradioactive isotope)		
Strychnine		

The target challenge concentrations were as follows:

- Chemicals: 1 ± 0.5 mg/L;
- *B. diminuta*: $\geq 1 \times 10^6$ CFU/100 mL; and
- MS2 and fr: $\geq 1 \times 10^4$ PFU/mL.

The M-2400 was plumbed to a test rig in the NSF testing lab and was calibrated for operation according to the instructions in the M-2400 operation manual.

The M-2400 was challenged with each organism or chemical individually, except for cadmium, cesium, and strontium, which were combined into one challenge. Each challenge was 30 minutes in length. For the microbial challenges, influent and permeate samples were collected for organism enumeration at start-up, after 15 minutes of operation, and after 30 minutes of operation. For the chemical challenges, influent and permeate samples were collected at start-up and 30 minutes. All samples were analyzed in triplicate.

The MAXVOC FF-975 was conditioned with water containing chloroform prior to being challenged. The purpose of the conditioning was to load the carbon with chloroform to a degree that simulated contaminant loading halfway through its effective lifespan. The MAXVOC FF-975 chemical challenges were also 30 minutes in length. As described above, the filter was only challenged with the chemicals that the RO membrane did not remove to 20 µg/L or below. Based on this criterion, the filter was challenged with chloroform, dichlorvos, mercury, and methomyl. The target challenge concentrations were the maximum permeate levels measured during the RO membrane challenges. The target flow rate for the challenges was 1.85 gpm, which was the highest permeate flow rate measured during the RO membrane challenges.

VERIFICATION OF PERFORMANCE

The results of the M-2400 microbial challenges are presented below in Tables VS-2 and VS-3. The triplicate influent and permeate counts for each sample point were averaged by calculating geometric means. The mean organism counts for each sample point were then averaged geometrically to give an overall mean influent and permeate count for each challenge. The overall mean counts are presented here. These counts were $\log_{10}$ transformed, and $\log_{10}$ reductions were calculated for each challenge.

Table VS-2. M-2400 Virus Challenge Results

Challenge	Mean Influent (PFU/mL)	$\log_{10}$ of Influent	Mean Permeate (PFU/mL)	$\log_{10}$ of Effluent	$\log_{10}$ Reduction
fr	9.4×10^4	5.0	121	2.1	2.9
MS2	5.5×10^4	4.7	49	1.7	3.1

Table VS-3. M-2400 Bacteria Challenge Results

Challenge	Mean Influent (CFU/100 mL)	$\log_{10}$ of Influent	Mean Permeate (CFU/100 mL)	$\log_{10}$ of Effluent	$\log_{10}$ Reduction
1st *B. diminuta*	2.0×10^7	7.3	5.7×10^4	4.8	2.5
KanR *B. diminuta*	7.0×10^6	6.9	2.8×10^3	3.4	3.5
2nd *B. diminuta*	6.9×10^6	6.8	1.1×10^4	4.1	2.7

The results of the M-2400 chemical challenges are presented in Table VS-4. The triplicate influent and permeate measurements were averaged by calculating the arithmetic mean. The means for each sample point were then averaged to give an overall mean influent and permeate for each challenge. As with the microbial challenge data, the overall means are presented here. Percent reductions were calculated from the influent and permeate concentrations.

Note that there are two entries in Table VS-3 for *B. diminuta*. A second challenge was conducted after it was noticed that the RO membrane operating pressure had risen above Watts Premier's recommended maximum of 150 psig (pounds per square inch, gauge). The system inlet pressure did not rise, but the membrane operating pressure created by the booster pump did rise after the system was initially calibrated with the operating pressure set at 150 psig. The recorded RO membrane operating pressures ranged from 160 to 172 psig for the microbial challenges and the cadmium/cesium/strontium, mercury, strychnine, paraquat, and aldicarb challenges. To see if the higher operating pressures affected the membrane's ability to filter out microorganisms, the *B. diminuta* challenge was conducted again. A comparison of the data in Table VS-3 does not indicate that the higher pressure affected membrane performance. The data from the chemical challenges at the higher pressures does not indicate that chemical rejection performance was compromised. Therefore, no other challenges were conducted again with a lower membrane operating pressure.

Table VS-4. M-2400 Chemical Challenge Results

Chemical	Mean Influent (μg/L)	Mean Effluent (μg/L)	Percent Reduction
Aldicarb	830	3	>99
Benzene	680	6.4	>99
Cadmium	970	1.4	>99
Carbofuran	920	2.6	>99
Cesium	1100	16	99
Chloroform	790	28	97
Dichlorvos	1700	16	>99
Mercury	1200	750	38
Methomyl	990	45	96
Mevinphos	920	5.6	>99
Oxamyl	1000	4	>99
Paraquat	480	ND (1)	>99
Sodium Fluoroacetate	800	ND (20)	98
Strontium	990	2	>99
Strychnine	900	ND (5)	>99

Based on the RO membrane permeate concentrations, the MAXVOC FF-975 filter was challenged with chloroform, dichlorvos, mercury, and methomyl. The results for these challenges are presented in Table VS-5. As with the RO membrane chemical challenge data, mean influents and effluents were calculated for each challenge. Percent reductions were then calculated using the overall mean influents and effluents.

Table VS-5. MAXVOC FF-975 Chemical Challenge Data

Chemical	Target Influent (μg/L)	Measured Mean Influent (μg/L)	Mean Effluent (μg/L)	Percent Reduction
Chloroform	72	82	3.2	96
Dichlorvos	25	36	ND (0.2)	>99
Mercury	910	730	10	99
Methomyl	48	56	1	98

The microbial challenges data shows that the M-2400 RO membrane alone can be expected to remove more than 2 logs (>99%) of bacteria and viruses from contaminated water. The RO membrane alone also removed greater than 96% of all challenge chemicals except mercury. The chemical challenges data in Tables VS-4 and VS-5 shows that the M-2400 and MAXVOC FF-975 combined would remove 99% or more of all challenge chemicals but sodium fluoroacetate, whose percent reduction was capped at 98% because of the high detection limit of 20 μg/L for the chemical.

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.

Original signed by Sally Gutierrez 09/22/06

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Availability of Supporting Documents

Copies of the test protocol, the verification statement, and the verification report (NSF report # NSF 06/23/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/etv
   EPA web site: http://www.epa.gov/etv