THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM

U.S. Environmental Protection Agency

NSF International

ETV Joint Verification Statement

TECHNOLOGY TYPE:	**MEMBRANE FILTRATION USED IN PACKAGED DRINKING WATER TREATMENT SYSTEMS**	
APPLICATION:	***GIARDIA* AND *CRYPTOSPORIDIUM* REMOVAL**	
TECHNOLOGY NAME:	**ULTRABAR ULTRAFILTRATION SYSTEM UTILIZING A MARK III MEMBRANE (60") ELEMENT**	
TEST LOCATION:	**PITTSBURGH, PA**	
COMPANY:	**THE F.B. LEOPOLD CO. INC.**	
ADDRESS:	**227 SOUTH DIVISION STREET** **ZELIENOPLE, PA 16063**	PHONE: **(724) 452-6300** FAX: **(724) 452-1377**
WEB SITE:	**http:\\www.fbleopold.com**	
EMAIL:	**gvegso@fbleopold.com**	

The U.S. Environmental Protection Agency (EPA) has created the Environmental Technology Verification (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 substantially 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; stakeholders groups which consist 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.

NSF International (NSF) in cooperation with the EPA operates the Package Drinking Water Treatment Systems (PDWTS) program, one of 12 technology areas under ETV. The PDWTS program recently evaluated the performance of a membrane filtration system used in package drinking water treatment system applications. This verification statement provides a summary of the test results for The F.B. Leopold Company Inc.'s. (Leopold) Ultrabar Ultrafiltration System. The specific model tested utilized a

60 inch membrane element with a Mark III series flow configuration (Leopold Ultrabar Mark III Ultrafiltration System). Gannett Fleming, Inc., an NSF-qualified field testing organization (FTO), performed the verification testing.

ABSTRACT

Verification testing of the Leopold Ultrabar Mark III Ultrafiltration System was conducted from February 3 to March 9, 1999. The performance claim evaluated during field testing of the Leopold Ultrabar Mark III Ultrafiltration System was that the system is capable of a minimum 3 log_{10} removal of Giardia cysts and 2 log_{10} removal of Cryptosporidium oocysts. The treatment system underwent microbial challenge testing on March 19, 1999, and demonstrated a 4.9 log_{10} removal of *Giardia* cysts and a 5.8 log_{10} removal of *Cryptosporidium* oocysts. The log_{10} removals were limited by the amount of the cysts and oocysts which were present in the stock feed solution, the percentage of the permeate that could be sampled, and the percent recovery of the analytical methodology. There were no *Giardia* cysts or *Cryptosporidium* oocysts observed in the permeate. Source water characteristics were: turbidity average 0.09 Nephlometric Turbidity Units (NTU), pH 7.8, and temperature 3.9°C. During the thirty-day verification test, the system was operated at a flux recommended by the manufacturer of 79 gallons per square foot per day (gfd) at 39°F which equates to 128 gfd at 68°F (133 liters per square meter per hour (l/m^2/h) at 3.9 °C, 216 l/m^2/h at 20 °C). The average transmembrane pressure was 9.8 pounds per square inch (psi) (0.68 bar [b]). The feed water recovery of the treatment system during the study was 98%. Chemical cleaning of the treatment system was conducted as part of the verification testing.

TECHNOLOGY DESCRIPTION

Ultrafiltration (UF) processes are generally used to remove microbial contaminants such as *Giardia* and *Cryptosporidium* and other particulate contaminants from drinking water. The Leopold Ultrabar Mark III ultrafiltration membrane is a hollow fiber made of modified polyethersulfone. It has a 0.01µm nominal pore size and utilizes inside-out flow. Water is applied under pressure to the inside of the hollow fiber membrane. The membrane consists of a thin film acting as a sieve. The membrane is a mechanical barrier, providing removal of particulate contaminants. Permeate (filtered water) is collected from the outside of the fiber and carried to the permeate outlet.

The Leopold Ultrabar Ultrafiltration System is a self-contained stand alone system installed in a 20-foot long sea-going (watertight) container. The container is heated, insulated and has lighting and electrical receptacles. The unit's floor is self-draining and the double doors are gasketed and lockable. The only required connections are for the water supply, a sewer connection for the discharge of backwash and chemical cleaning wastes and electrical service. The treatment system consists of two membrane modules, supply pump, feed water and backwash reservoirs and pumps, chemical cleaning equipment and necessary gauges and controls. The treatment system is capable of operating in an automatic mode with limited operator intervention.

For this test program, a dead end filtration mode was used. In dead end mode, all the water exits through the porous hollow fiber at a selected flow rate. During the filtration cycle the feed flow rate equaled the permeate flow rate. To maintain stable flow over the short term, a backwash cycle was performed. At a preset time, determined by raw water quality, the membrane was backwashed. This was accomplished by reversing the flow direction; forcing the permeate back through the fibers from outside to inside. Approximately once per week a chemically enhanced backwash was performed. Although the procedure was varied somewhat during the verification testing, the enhanced backwash generally consisted of a 30 second backwash with permeate, followed by a 45 second backwash with permeate to which 200 mg/l of NaOCl was added, then allowing the membrane to soak in the 200 mg/l NaOCl solution for 5 minutes, and finally a 45 second rinse with permeate.

VERIFICATION TESTING DESCRIPTION

Test Site

The verification testing site was the Pittsburgh Water and Sewer Authority's (PWSA's) open air Highland Reservoir No. 1, Pittsburgh, Pennsylvania. The source water for the verification testing was treated surface water drawn from the Allegheny River. It underwent coagulation, sedimentation, filtration, and disinfection at PWSA's Aspinwall Treatment Plant prior to being pumped to the Highland Reservoir No. 1. The influent to the treatment unit was drawn from the reservoir effluent lines. The verification testing was limited to the performance of the equipment to remove *Cryptosporidium* oocysts and *Giardia* cysts, because the source water was obtained from an open reservoir.

Methods and Procedures

All field analyses (i.e. pH, turbidity, chlorine residual, temperature) were conducted daily using portable field equipment according to Standard Methods for the Examination of Water and Waste Water, 18th Ed., (APHA, et. al., 1992). Likewise, Standard Methods, 18th Ed., (APHA, 1992) and Methods for Chemical Analysis of Water and Wastes (EPA, 1979) were used for analyses conducted in PWSA's laboratory. These analyses included total alkalinity, total hardness, total organic carbon (TOC), dissolved organic carbon (DOC), total dissolved solids (TDS), total suspended solids (TSS), algae (number and species), Ultraviolet Absorbance at 254 nanometers (UVA_{254}), total coliform, and heterotrophic plate counts (HPC). Total alkalinity, total hardness and TDS analyses were conducted monthly. All other laboratory parameters were analyzed weekly.

Microbial challenge was performed using *Giardia* cysts and *Cryptosporidium* oocysts. Procedures developed by EPA for use during the Information Collection Rule (ICR) were employed for the identification and enumeration of *Giardia* cysts and *Cryptosporidium* oocysts (EPA, ICR Microbial Laboratory Manual, EPA, April 1996). The protozoans were added to a fifty (50) gallon (190 liter) drum. This drum was filled with the feed water. A total of 13,800,000 *Giardia* cysts and 98,947,000 *Cryptosporidium* oocysts were added to the feed water reservoir. The turbidity of the feed water was 0.09 NTU at the beginning of the microbial removal challenge testing and decreased to 0.06 NTU at the conclusion of the testing. This stock suspension was constantly mixed using a drum mixer. A diaphragm pump was used to add the protozoans to the membranes on the pilot unit. The pump was operated at about 0.85 gallons per minute (gpm) (3.2 liters per minute) and was capable of overcoming the pressure in the feed water line of the pilot unit. Samples of the permeate were collected using a polypropylene wound filter with a nominal pore size of 1.0 µm. One thousand liters (264 gallons) of permeate water were filtered through the sampling vessel at one gpm (3.8 liters per minute). In addition, aliquots of the stock suspension were collected and analyzed to calculate concentrations of the microbes in the feed water. Backwash was delayed until the end of the collection period. Samples of the backwash were collected and analyzed to verify that the parasites were added to the system and removed by the filters.

VERIFICATION OF PERFORMANCE

System Operation

The treatment system was fully automated and capable of normal operations without manual intervention. The unit automatically operates in the filtration and backwash modes. All operational data, flows, pressures, turbidity, and particle counts are recorded on data logging software. Manual intervention is required for chemical cleaning and to occasionally refill the tank of sodium hypochlorite used during chemically enhanced backwash.

The system was operated at a flux recommended by the manufacturer, 79 gfd at 39°F which equates to 128 gfd at 68°F (133 l/m^2/h at 3.9 °C, 216 l/m^2/h at 20 °C. The flow rate was recorded twice per day and the water temperature was recorded once per day. The flow rate of the treatment system averaged 41 gpm (160 liters per minute).

The feed and permeate pressures were recorded twice per day. The average feed pressure was 19 psi (1.3 b). The average permeate pressure was 9.1 psi (0.63 b). The amount of pressure lost as the water is filtered through the membrane is referred to as transmembrane pressure (TMP). It is calculated by subtracting the permeate water pressure from the feed water pressure. The average TMP for the system was 9.8 psi (0.68 b). For this test program, a backwash interval of once every 60 minutes was used. Approximately 50 gallons of permeate was used to backwash the membranes.

The percent water recovery of the treatment system during the study was 98%. This figure was calculated by comparing the amount of water needed to backwash the membranes to the total amount of water filtered by the system.

The effectiveness of the chemical cleaning process was measured by the recovery of specific flux and loss of original specific flux. Chemical cleaning was conducted at the end of the test period as required by the ETV Protocol for Equipment Verification Testing for Physical Removal of Microbiological and Particulate Contamination (EPA/NSF April, 1998). Data collected before and after the chemical cleaning were used to calculate recovery of specific flux and the loss of original specific flux. The chemical cleaning recovered 11% of the specific flux. The membranes used in the verification testing were placed into service less than one month prior to the beginning of the testing and were not experiencing a significant loss of flux. This may account for the low recovery of specific flux. Data from when the membranes were placed into service and just after cleaning were used to calculate the loss of original specific flux. The loss of original specific flux was 0.43%. This result may be due to the relative age of the membrane and not the effectiveness of the cleaning procedure.

System integrity was demonstrated as required by the ETV protocol. Tests were conducted on an intact membrane system and on one that had been intentionally compromised. The air pressure hold test detected a compromised membrane.

Water Quality Results

During the microbial challenge testing that occurred on March 19, 1999, the Leopold Ultrabar Mark III Ultrafiltration System demonstrated a 4.9 $\log_{10}$ removal of *Giardia* cysts and a 5.8 $\log_{10}$ removal of *Cryptosporidium* oocysts. The $\log_{10}$ removals were limited by the amount of the parasites which were present in the stock feed solution, the percentage of the permeate that could be sampled, and the percent recovery of the analytical methodology. There were no *Giardia* cysts or *Cryptosporidium* oocysts observed in the permeate. During the microbial challenge testing, the feed water characteristics were: turbidity average 0.09 NTU, pH 7.7, temperature 4.7 °C.

During the thirty-day ETV operation of the Leopold Ultrabar Mark III Ultrafiltration System, treatment reductions were seen in HPC, algae, turbidity, and particle counts. HPC concentrations averaged 111 colony forming units (cfu)/100ml in the feed water and 22 cfu/100ml in the permeate. The presence of HPC in the permeate may have been due to inadequate disinfection of the Tygon tubing used for water sampling. Algae concentrations averaged 14 cells/ml in the feed water and <8 cells/ml in the permeate. Turbidity was reduced from an average of 0.09 NTU in the feed water to 0.05 NTU in the permeate. These results were from readings taken from the bench top turbidimeter. The inline permeate turbidimeter did not appear to be operating reliably throughout the verification testing. Particle counts were reduced from an average of 100 total counts/ml in the feed water to an average 3.3 total counts/ml in the permeate.

Total coliform reduction could not be demonstrated due to the absence of total coliforms in the feed water and permeate throughout the test. The following table presents the water quality reductions of the feed water and filtered water samples collected during the 30 days of operation:

Feed Water Quality / Filtered Water Quality
Leopold Ultrabar Mark III Ultrafiltration System

	Total Coliforms (cfu/100 ml)	HPC (cfu/100 ml)	Algae (cells/ml)	Turbidity (NTU)	Particle Counts (particles/ml)
Average[1]	0/0	111/22	14/<8	0.09/0.05	100/3.3
Minimum[1]	0/0	28/8	<8/<8	0.06/0.04	----
Maximum[1]	0/0	188/58	32/<8	0.13/0.10	----
Standard Deviation [1]	0/0	71/21	11/0	0.02/0.00	----
95% Confidence Interval[1]	N/A/ N/A	(48, 173)/ (3, 40)	(4, 23)/ N/A	(0.08, 0.09)/ (0.04, 0.05)	----

1 – Concentration of feed water/concentration of filtered water.
N/A = Not Applicable because standard deviation = 0
---- = Statistical measurements on cumulative data not calculated.
Note: Calculated averages for less than results (<) utilize half of the Level of Detection (Gilbert, 1987).

Temperature of the feed water was fairly stable during the thirty day testing from a low of 3.3°C to a high of 4.5°C. The average temperature was 3.9°C. The membrane pilot unit had little or no effect on total alkalinity, total hardness, TOC, TSS, TDS, and UVA_{254}.

Operation and Maintenance Results

Maintenance requirements on the treatment system did not appear to be significant but were difficult to quantify due to the short duration of the study. There were three interruptions of the process during the testing period. The first interruption occurred February 13 when the FTO's field representative broke the permeate sample line during sample collection. The sample line was broken before the shut off valve and the unit had to be shut down. Repairs were made and the system was restarted on February 16. The second interruption occurred on February 25. The treatment unit's display screen indicated that a low air pressure alarm was the cause of the shutdown. No malfunction of the unit's air system was found. The unit was restarted and back in service February 26. The third failure occurred on February 27. The treatment unit's display screen indicated that a low level in the feed water reservoir had caused the shut down. Due to the lack of available feed flow it was necessary to slightly decrease the flow rate through the unit to maintain operation of the system.

The Operating and Maintenance (O&M) Manual provided by Leopold was available for review on-site and was referenced occasionally during the testing. Particularly, the manual was consulted during the cleaning procedure. The manual was well organized and a valuable resource during the testing period.

Original Signed by
E. Timothy Oppelt *7/27/00*
E. Timothy Oppelt Date
Director
National Risk Management Research Laboratory
Office of Research and Development
United States Environmental Protection Agency

Original Signed by
Tom Bruursema *7/28/00*
Tom Bruursema Date
General Manager
Environmental and Research Services
NSF International

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Availability of Supporting Documents

Copies of the *ETV Protocol for Equipment Verification Testing for Physical Removal of Microbiological and Particulate Contaminants* dated April 20, 1998 and revised May 14, 1999, the Verification Statement, and the Verification Report (NSF Report #00/10/EPADW395) are available from the following sources:
(NOTE: Appendices are not included in the Verification Report. Appendices are available from NSF upon request.)

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

2. NSF web site: http://www.nsf.org/etv (electronic copy)

3. EPA web site: http://www.epa.gov/etv (electronic copy)