THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM

U.S. Environmental Protection Agency

NSF International

ETV Joint Verification Statement

TECHNOLOGY TYPE:	**OZONE DISINFECTION SYSTEM USED IN DRINKING WATER TREATMENT SYSTEMS**	
APPLICATION:	**INACTIVATION OF *CRYPTOSPORIDIUM* OOCYSTS AND CALCULATION OF CT IN DRINKING WATER**	
TECHNOLOGY NAME:	**MODEL PS 150 OZONE DISINFECTION SYSTEM**	
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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 Drinking Water Treatment Systems (DWTS) Pilot, one of 12 technology areas under ETV. The DWTS Pilot recently evaluated the performance of an ozone disinfection system used in drinking water treatment system applications. This verification statement provides a summary of the test results for the Osmonics Model PS 150 Ozone Disinfection System. Cartwright, Olsen and Associates, an NSF-qualified field testing organization (FTO), performed the verification testing.

ABSTRACT

Verification testing of the Osmonics Model PS 150 Ozone Disinfection System was conducted for 216 hours of continuous operation between December 5, 1999 and December 14, 1999, and *Cryptosporidium parvum* (*C. parvum*) challenges were performed on December 5 through December 7, 1999. Between December 5 and December 14, 1999, raw water characteristics were: average pH 7.7, temperature 5.5°C, turbidity 0.14 Nephlometric Turbidity Units (NTU), total alkalinity 35 mg/L, and total hardness 64 mg/L. Average flow rate over the test period was 164.4 gpm. During the *C. parvum* challenges the raw water characteristics were: pH 7.74-8.12, temperature 5.4-6.2°C, flow rate 164.4-165.5 gpm and inlet water pressure 12-16 psig. The system demonstrated –0.01 to 0.62 $\log_{10}$ inactivation of *C. parvum* oocysts and CT values between 6.78 and 19.35 based on the log integration method and between 4.34 and 11.45 based on the conservative method (see Chapter 4 for details).

TECHNOLOGY DESCRIPTION

All components of the system (with the exception of the contact tank) are assembled as a package in a skid and frame configuration. The system is equipped with a control panel and process logic controller, power supply, transformer, and fail-safe monitoring controls. The Model PS 150 includes a high efficiency ozone generator, a stainless steel side stream booster pump, a Venturi injector, a small stainless steel dissolution chamber, a cyclonic degas stripper, a stainless steel ozone contact tank, and an ozone off-gas destruct unit.

Physical dimensions of skid/frame are 10’ wide × 5’ deep × 6’ high, and weighs 4,000 pounds. The contact tank measures 60” diameter × 144” height, and weighs 1,000 pounds. Total combined shipping weight is 5,000 pounds and is suitable for easy transportation.

The ozone generator is a model HC-2, high efficiency, cabinet style unit with a maximum rated output of 20 pounds/day at 6% weight concentration. It is a high frequency generator, operating at 7 kHz. The power supply is 230 VAC, 60 Hz, 3 phase, with 30 amps per phase circuit protection. Ozone is produced when oxygen gas enters the generator and passes through an electric field. This electric field excites the oxygen into ozone. This ozone and oxygen mixture then flows out of the generator to be mixed with the water at the injector.

The Model PS 150 allows the operator to select the CT value applied to influent water via a control screen located on the front of the unit. The control screen is driven by a programmable logic controller (PLC), electronically connected to a water flow rate meter and on-line dissolved ozone sensors located at the inlet and outlet of the Model PS 150’s ozone contacting system. The controller achieves and maintains CT values desired by the operator by taking the average of the inlet and outlet dissolved ozone readings and multiplying this number by the systems’ hydraulic retention time (minutes) and value (T_{10}/T_{theory}). The Model PS 150 system provided for this ETV study had been programmed with a total retention volume of 1,200 gallons and a hydraulic value (T_{10}/T_{Theory}) of 0.5.

The PLC automatically increased power to the ozone gas generator if the PLC calculated CT value started to fall below the set point thus increasing ozone gas concentration produced. This increase elevated the amount of ozone dissolved into solution, thus maintaining the CT value at its original set point. The reverse would occur if a CT value started to increase above the original set point.

The Model PS 150 is designed to be a final barrier for microbiological contaminants, including *G. lamblia* and *C. parvum.* Accordingly it is intended the Model PS 150 be installed to treat water that has been filtered to a level 1 NTU turbidity.

VERIFICATION TESTING DESCRIPTION

Test Site

The host site for this demonstration was the University of Minnesota St. Anthony Falls Hydraulic Laboratory (SAFHL), which has direct access to untreated and treated Mississippi river water. SAFHL is located on the Mississippi River at Third Avenue S.E., Minneapolis, Minnesota 55414. Influent to the Osmonics Model PS 150 Ozone Disinfection system was finished water from the Minneapolis Public Water Distribution System which had been dechlorinated previous to entry into the equipment test station.

Methods and Procedures

The verification test was divided into tasks that evaluated the system's treatment performance, specifically its ability to inactivate *G. lamblia* cysts and *C. parvum* oocysts in the influent, and documented the system's operational parameters.

Water quality parameters that were monitored during the verification test included: pH, temperature, turbidity, dissolved ozone residual, total chlorine, color, total alkalinity, total hardness, total organic carbon (TOC), ultraviolet absorbance (UVA) at 254 nanometer (nm), iron, calcium hardness, manganese, dissolved organic carbon, total sulfides, bromide, bromate, total trihalomethanes (TTHMs – in effluent only), and haloacetic acids (HAAs – in effluent only). Laboratory analyses were performed in accordance with the procedures and protocols established in *Standard Methods for the Examination of Water and Wastewater,* 19^{th} Edition *(SM)* or EPA-approved methods.

Hydraulic retention time of ozonated water was verified with the use of tracer studies. Salt brine was injected through a metering pump into the feed stream of the ozone system to provide an elevated marker TDS of approximately three times over the baseline level. TDS meters were used to measure for increases in TDS every 15 seconds from sample ports located at the point of ozone injection and immediately after the contact tank. From this data a T_{10} value was calculated in accordance with the Guidance Manual for the Surface Water Treatment Rule in order to establish the hydraulic retention value provided by the equipment package being tested.

The Model PS 150 was challenged with live *C. parvum* oocysts. The objective of this task was to determine the CT capabilities of the Model PS 150 and to determine the $\log_{10}$ inactivation achieved during these tests. The challenge consisted of the following steps:

1) The introduction of live *C. parvum* oocysts into the water stream and their passage through the Model PS 150,
2) The recovery of the oocysts from the water stream,
3) The determination of level of oocyst infectivity,
4) The calculation of $\log_{10}$ inactivation.

The following table is a summary of the *C. parvum* challenge seeding schedule design:

Cryptosporidium parvum **Challenge Seeding Schedule Design**

Date	Run Type (Ozone Dose)	Flow Rate	CT
12/5/99	High	150 GPM	15
12/5/99	Medium	150 GPM	10
12/5/99	Medium	150 GPM	10
12/6/99	Medium	150 GPM	10
12/6/99	Low	150 GPM	5
12/7/99	Process Control	150 GPM	0

System effluent water was tested downstream of sodium thiosulfate injection to verify no dissolved ozone was present prior to the oocyst seeding. The entire effluent stream from Model PS 150 (and contact tank) was diverted through a stainless steel housing containing four 3" diameter by 20" long 1.0 μm absolute track-etch polycarbonate membrane filter cartridges (Nucleopore, Inc.). The surface area of each filter was 2.8 m^2 (30.14 ft^2) for a total filter area of 120.5 ft^2. At 150 gpm the approach flowrate was 1.24 gpm/ft^2. Protozoan oocyst injection utilized a 100 mL graduated cylinder into which a suspension of approximately 2.0 x 10^8 to 4 x 10^8 oocysts was placed. A 44 gpd Pulsatron Model LPKSA PTC2 metering pump equipped with PTFE tubing injected the organisms into the feed stream at a rate of 50 mL/min. A neonatal mouse model was used to evaluate infectivity of *C. parvum* oocysts. The number of oocysts in each experimental sample was determined using immunofluorescence (IF) straining. Logistic analysis, as proposed by Finch, et al. (1993), was used for analyzing oocyst dose-response data. This method applies a logarithmic transformation that converts the normal dose-response data into a form that can be readily analyzed by linear regression.

CT values were calculated during *C. parvum* challenge seedings. The measured CT values were compared to the CT values for log_{10} inactivation for *G. lamblia* and virus accepted by the USEPA.

VERIFICATION OF PERFORMANCE

Source Water

Between December 5 and December 14, 1999, raw water characteristics were: average pH 7.7, temperature 5.5°C, turbidity 0.14 Nephlometric Turbidity Units (NTU), total alkalinity 35 mg/L, and total hardness 64 mg/L. Average verified flow rate over the test period was 164.4 gpm. During the *C. parvum* challenges the raw water characteristics were: pH 7.74-8.12, temperature 5.4-6.2°C, flow rate 164.4-165.5 gpm and inlet water pressure 12-16 psig.

Hydraulic Retention Time

Total retention volume of the PS 150 was verified at 1,610.4 gallons (as compared to 1,200 gallons estimated by Osmonics) and challenge flow rate was verified at 164.4 gpm. Hydraulic tracer tests provided an estimated T_{10} value of 4.0 minutes. Given a T_{theory} value 9.8 minutes (1,610.4 gallons/164.4 gpm) the hydrodynamic value of the contactor is represented as 0.41 (T_{10}/T_{theory}). The T_{10} value represents the minimum length of time for which 90 percent of the water will be exposed to the disinfectant within the contactor while T_{theory} represents the theoretical hydraulic detention time of the contactor assuming plug flow (calculated by dividing the total volume of the contractor by the water flow rate).

Operation and Maintenance

A recurring issue that was problematic to the operation of the Osmonics Model PS 150 involved the operators' ability to set (or change) the CT value achieved by the system via the controller's menu screen. The O&M manual described the ability for an operator to change an applied CT value (ozone dose) delivered by the equipment package by keying in the desired value on a menu screen. This feature did not function during the course of the testing period. Accordingly, CT values were changed by adjusting power supplied to the ozone generator until the CT value displayed on the controller's output screen reached the desired level.

Another issue that proved to be problematic to the operator involved resetting the normally open solenoid valve located on the ozone gas delivery line between the venturi and the ozone generator. This valve automatically closes upon the detection of water droplets within the gas delivery line, thus preventing the passage of water in the event of a check valve failure. Unfortunately, once the solenoid valve closed, it did not reopen once the water droplets had been removed. It was discovered with manipulation of the PLC, the valve would open, but not without significant manual intervention. The O&M manual provided by the manufacturer primarily defined installation, operation and maintenance requirements for Osmonics Model PS 150. The manual provided information pertaining to basic installation, start-up, and operational process. A process schematic, trouble shooting guide, and associated O&M manuals for components used within the system were also provided. The O&M manual was reviewed for completeness and used during equipment installation, start-up, system operation, and trouble-shooting. It was found the manual provides adequate instruction for tasks required to perform these functions over the period of operation of the ETV test period.

Protozoan Contaminant Removal

The system demonstrated –0.01 to 0.62 $\log_{10}$ inactivation of *C. parvum* oocysts and CT values between 6.78 and 19.35 based on the log integration method and between 4.34 and 11.45 based on the conservative method. These results were obtained at an average flow rate of 164.4 gpm. These CT values are a surrogate for the disinfection effectiveness of the Model PS 150 treating water at a pH of 7.74-8.12 and a temperature range of 5.4-6.2°C for *G. lamblia* and virus inactivation.

Finished Water Quality

A summary of the effluent water quality information for the verification period of December 5, 1999 through December 14, 1999 is presented in the following table.

Effluent Water Quality (December 5 - 14, 1999)

Parameter	# of samples	Average	Minimum	Maximum	Standard Deviation	95% Conf. Interval	PQL
Bromide (mg/L)	6	<1.0	<1.0	<1.0	NA	NA	1.0 mg/L
Bromate (mg/L)	6	<2.0	<2.0	<2.0	NA	NA	2.0 mg/L
Dissolved Manganese (mg/L)	6	<0.01	<0.01	<0.01	NA	NA	0.01 mg/L
Total Manganese	6	<0.01	<0.01	<0.01	NA	NA	0.01 mg/L
Total Trihalomethanes (ì g/L)	6	0.5	<0.5	0.6	NA	NA	0.5 µg/L
Ion Chromatography *(Dichlorobromacetate) (mg/L)	6	1.3	1.2	1.5	NA	NA	0.5 mg/L
UV_{254} (cm^{-1})	9	0.027	0.021	0.037	0.005	0.024, 0.040	-

*When Ion Chromatography detected a positive result, further speciation concluded Dichlorobromacetate.

Power Consumption

Power consumption during the verification period totaled 699 kW hours and represented the total cost of operation. During the 216 hours of continuous operation the Model PS 150 system treated 1.944 million gallons of water resulting in an average power requirement of 359.57 kW hours per 1 million gallons treated.

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Availability of Supporting Documents

Copies of the *ETV Protocol for Equipment Verification Testing for Inactivation of Microbiological Contaminants* dated August 9, 1999, the Verification Statement, and the Verification Report (NSF Report # 01/15/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 Treatment 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)