September 2000
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Environmental Technology Verification Report

On-Site Generation of Sodium Hypochlorite

ClorTec, a Division of Capital Controls, Inc.
ClorTec Model MC 100

Prepared by

NSF International

Under a Cooperative Agreement with

U.S. Environmental Protection Agency

THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM

U.S. Environmental Protection Agency

NSF International

ETV Joint Verification Statement

TECHNOLOGY TYPE:	**ON-SITE GENERATION OF HALOGEN DISINFECTANTS USED IN PACKAGED DRINKING WATER TREATMENT SYSTEMS**
APPLICATION:	**ON-SITE GENERATION OF SODIUM HYPOCHLORITE**
TECHNOLOGY NAME:	**CLORTEC MODEL MC 100 SYSTEM**
COMPANY:	**CLORTEC, A DIVISION OF CAPITAL CONTROLS, INC.**
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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 on-site sodium hypochlorite generation (SHG) system used in package drinking water treatment system applications. This verification statement provides a summary of the test results for the ClorTec Model MC 100 System. Gannett Fleming Inc., an NSF-qualified field testing organization (FTO), performed the verification testing.

ABSTRACT

The EPA and NSF verified the performance of the ClorTec Model MC 100 System under the EPA's ETV program. The concentrated hypochlorite generator stream from the treatment system underwent a twice-daily analysis from March 8 to April 6, 2000. The chlorine analyses were conducted on site in United Water Pennsylvania's Hummelstown Water Treatment Plant (WTP) operators lab. The hypochlorite generator stream was analyzed using two methods of measuring total chlorine: *Standard Method* 4500-Cl F (EPA approved) and *Standard Method* 4500-Cl B. The average sodium hypochlorite concentration was 0.90% ± a standard deviation of 0.04% using *Standard Method* 4500-Cl B and 0.91% ± a standard deviation of 0.08% using *Standard Method* 4500-Cl F. The average sodium chloride concentration in the brine fed to the generator electrolytic cells during the verification testing was 3.53%, higher than ClorTec's specified value of 3.0%. The average DC current and voltage applied to the electrolytic cells during the ETV were 183 amps and 46 volts, respectively. ClorTec states that the amperage and voltage should be approximately 185 amps and 48 volts. No attempt was made to adjust the brine pump feed rate during the verification testing; it is factory set to deliver the concentrated brine (30% sodium chloride) to a softened side stream from the WTP finished water by a ratio of approximately ten parts water to one part brine prior to entering the generator. After the tenth day of testing, the chlorine concentration in the hypochlorite concentrate stream generally trended higher. This roughly correlated with a higher sodium chloride concentration.

TECHNOLOGY DESCRIPTION

On-site sodium hypochlorite generation systems for drinking water treatment are used in place of gas chlorine for primary and/or residual disinfection. The concentration of on-site generated sodium hypochlorite is typically less than 1%, sufficiently dilute so that the generation equipment does not require special handling or containment.

The process involves the application of a low-voltage DC current to a brine containing an approximate 3.0% sodium chloride concentration to generate a sodium hypochlorite concentration of approximately 0.8%. The generation process occurs inside clear four inch PVC tubes housing ten pairs of anode and cathode electrolytic plates. Current is applied to the electrolytic plates as the brine is pumped between the plates. The product generated from this reaction is sodium hypochlorite, plus the byproduct hydrogen. The cells are designed so that the hydrogen is readily separated from the sodium hypochlorite and vented to the outside.

The ClorTec Model MC 100 system is a modular system whose primary components consist of a power supply and rectifier, brine pump and electrolytic cells, and a Programmable Logic Controller (PLC)-based control panel. A brine saturator and day tank, water softener, sodium hypochlorite storage tanks and metering pumps are required in addition to the modular components. The system operates in the automatic batch mode based on setpoints entered into the PLC and liquid level signals transmitted back from the hypochlorite storage tanks. Only limited operator intervention is required.

The ClorTec Model MC 100 system is designed to produce up to 100 pounds per day of sodium hypochlorite as chlorine.

VERIFICATION TESTING DESCRIPTION

Test Site

The test site was United Water Pennsylvania's Hummelstown WTP. The water source for this plant is the Swatara Creek, a supply that can vary significantly in water quality, particularly turbidity, pH, alkalinity and hardness. The plant is a conventional WTP consisting of prechlorination, coagulation, clarification, granular media filtration and post chlorination. The pre- and post chlorination was supplied by the ClorTec Model MC 100 sodium hypochlorite generation system, permanently installed in the chemical room of the WTP. For monitoring purposes, the post chlorine feed point was selected as the ETV testing location.

Methods and Procedures

Measurement of the equipment's physical parameters occurred at least once daily during the ETV test period. This includes monitoring brine and sodium hypochlorite storage tank levels; feed water, brine dilution water and treated water flow rates; brine specific gravity; dilution water and brine temperatures; on-line analyzer sample flow rates; and rectifier amperage and voltage.

Softener waste stream flow rate and composition were also noted during the ETV test period.

All field analyses (i.e. pH, turbidity, chlorine residual, temperature and hydrogen sulfide) were conducted daily or, in the case of chlorine residual, twice daily, using bench test equipment in accordance with *Standard Methods for the Examination of Water and Wastewater*, 19^{th} Ed. (1995).

All laboratory analyses were conducted by Microbac Laboratories (Microbac) using procedures from *Standard Methods* or EPA-approved methods. These analyses included the following inorganic parameters: alkalinity, ammonia nitrogen, UV_{254}, and true color, which were analyzed weekly and TDS, iron, manganese, chloride, bromide, and sodium, which were analyzed once during the test period. The disinfectant byproduct parameters analyzed by Microbac were chlorite, chlorate, total trihalomethanes (TTHMs) and haloacetic acids (HAA5). Samples were analyzed by Microbac five days per week for total coliform and heterotrophic plate counts.

Simulated Distribution System (SDS) Disinfectant Byproduct (DBP) Formation Testing was performed due to the fact that the ClorTec Model MC 100 system is used as the chlorine source for both primary disinfection and residual disinfection. The uniform formation conditions (UFC) of the EPA Information Collection Rule (ICR) were followed to estimate DBP formation in the distribution system, including TTHMs using EPA Method 524.2, HAA5 using *Standard Method* 6251B, and chlorite and chlorate, both using EPA Method 300.0.

VERIFICATION OF PERFORMANCE

System Operation

As previously indicated, the system operated in the auto batch mode. Generator operation was initiated based on the sodium hypochlorite level in the storage tanks. A 4-20 mA signal from level transmitters situated on top of each storage tank was sent to the PLC controller, which would activate the generator from standby if the levels in the hypochlorite storage tanks were below the previously entered setpoint. Generator operation was terminated based on sodium hypochlorite levels in the storage tanks reaching a previously entered high level setpoint. This mode of operation was effective during the ETV.

The number of SHG continuous hours of operation was primarily contingent on the WTP production rate, and varied from 3 hours to 25 hours with an average of 13 hours. The hypochlorite metering pumps, which are not an integral part of the ClorTec MC 100 system, typically had to be adjusted manually several times daily to account for this operating variable (there was no pacing system for the metering pumps).

No adjustments were made to the SHG dilution water flow, voltage or amperage during the ETV because these parameters and the brine specific gravity were within the ranges specified in the *ClorTec MC Operator Interface PLC Manual.*

Water Quality Results

The feed water turbidity was low due to coagulation/clarification/filtration of the raw water by the Hummelstown WTP, averaging 0.067 NTU during the verification testing. A free chlorine residual was maintained in the feed water, averaging 0.36 mg/l during the test period. Due to the high quality filtered water and the chlorine demand having been satisfied with prechlorination, the addition of post sodium hypochlorite provides a free available chlorine residual for achieving compliance with CT requirements under the EPA Surface Water Treatment Rule (SWTR), and provides a residual disinfectant throughout the distribution system.

Table 1 summarizes the results of on-site analytical testing for the 30 day verification test. The only change in water quality of any significance between the feed water and treated water was the concentration of chlorine. The addition of post sodium hypochlorite resulted in an average total chlorine concentration of 1.46 mg/l, an increase of 0.95 mg/l over feed water total chlorine level. As stated previously, the treatment prior to post sodium hypochlorite either removed or satisfied almost all of the chlorine demand, resulting in post chlorine being available largely as free chlorine. Temperature of the feed water averaged 11.4ºC. Hydrogen sulfide was not detected in the feed water; the minimum method detection level for hydrogen sulfide was 0.1 mg/l.

Table 1. On-Site Water Quality Analyses

	Feed Water (Filter Room Pumped Sample)						Treated Water (Finished Water - Lab Sink)							Hypochlorite Generator	
		Turbidity							Turbidity		FAC			TAC	
	Bench pH	Bench (NTU)	On-line (NTU)	Bench H_2S (mg/l)	On-line FAC (mg/l)	TAC FAS[1] (mg/l)	On-line pH	Bench pH	Bench (NTU)	On-line (NTU)	FAS[1] (mg/l)	On-line (mg/l)	TAC FAS[1] (mg/l)	FAS[1] (%)	Iodo[2] (%)
Mean	7.0	0.067	0.060	0	0.36	0.51	7.07	7.0	0.063	0.059	1.33	1.23	1.46	0.91	0.90
Minimum	6.2	0.040	0.040	0	0.01	0.08	6.80	6.5	0.046	0.040	1.05	1.00	1.00	0.80	0.78
Maximum	7.6	0.100	0.094	0	1.38	1.58	7.53	7.4	0.100	0.098	1.80	1.69	2.00	1.11	0.97
Std Dev	0.3	0.017	0.014	0	0.24	0.29	0.15	0.2	0.013	0.014	0.17	0.16	0.22	0.08	0.04
95% Conf	7.0±	0.067±	0.060±	N/A	0.36±	0.51±	7.07±	7.0±	0.063±	0.059±	1.33±	1.23±	1.46±	0.91±	0.90±
Interval	0.1	0.006	0.005		0.06	0.07	0.05	0.1	0.005	0.005	0.04	0.04	0.05	0.02	0.01

(1)FAS=Ferrous Ammonium Sulfate Titration (Standard Method 4500-Cl F)
(2)Iodo=Iodometric Titration (Standard Method 4500-Cl B)
FAC=Free Available Chlorine
TAC=Total Available Chlorine

Total Coliform, indicator bacteria for potential fecal contamination, and Heterotrophic Plate Count (HPC), a general indicator for total bacterial levels, were sampled five days per week for the test period. There were no positive indications for the presence of Total Coliform in either the feed water or treated water. HPC were detected in two feed water samples at 15 and 73 colony forming units (cfu)/ml and three treated water samples at 1, 58 and 71 cfu/ml. The dates that exhibited the two higher detections in the treated water corresponded to the sample dates of the two detections in the feed water. There is no indication in the WTP operating records or the ETV logbook of having lost hypochlorite feed during the sampling period when HPC were detected. The most likely reason for the detections was improper sampling procedures.

Six inorganic contaminants commonly found in water supplies were analyzed in the feed water and treated water once during the test period. Iron, manganese and bromide were below detection limits in both the feed water and treated water. TDS increased from 139 mg/l in the feed water to 147 mg/l in the treated water; sodium increased from 11.6 mg/l to 13.3 mg/l; and chloride increased from 23.8 mg/l to 27 mg/l. The TDS of the softener wastewater was much higher (7785 mg/l) than the feed water due to the removal and concentration of dissolved minerals in the softener treatment process. These increases in TDS, sodium and chloride are likely due to the addition of sodium hypochlorite to the feed water process.

The presence of ammonia can have a significant impact on disinfection due to the demand it places on chlorine. No ammonia was detected in either the feed water or treated water. The impact of feeding sodium hypochlorite on the alkalinity level was negligible, increasing it from an average of 28 mg/l as $CaCO_3$ to 30 mg/l as $CaCO_3$. Feed water and treated water alkalinity levels were, with the exception of one set of samples, the same.

UV_{254} and true color are parameters commonly used as indicators of the relative concentration of natural organic matter (NOM). The primary significance of NOM is as potential precursors for producing disinfection byproducts when combined with a disinfectant such as chlorine. The levels of UV_{254} and true color were relatively low, with no significant difference between the feed water and treated water.

Organic and inorganic disinfectant byproducts are presented on Table 2.

Table 2. Disinfectant Byproduct Analyses

Parameter	Feed Water (mg/l)	Treated Water (mg/l)
TTHM - Inst.	0.0140	0.0160
HAA5 - Inst.	0.0060	0.0187
TTHM - SDS	NT	0.0390
HAA5 - SDS	NT	0.0277
Chlorite - Inst	<0.02	<0.02
Chlorate - Inst	0.081	0.112
Chlorite - SDS	NT	<0.02
Chlorate - SDS	NT	0.262

Inst.=Instantaneous
SDS=Simulated Distribution System
NT=Not Tested

As indicated on Table 2, instantaneous analyses were conducted on both the feed water and treated water samples for TTHM and HAA5. DBP levels were anticipated to be higher in the treated water relative to the feed water due to the addition of post sodium hypochlorite and the additional contact time in the WTP finished water storage. As expected, TTHM and HAA5 levels were higher in the treated water, although only slightly for TTHM. In contrast, HAA5 levels increased by a factor of three.

A portion of the treated water sample was subject to UFC, as defined under the EPA ICR, for the purpose of producing SDS samples. These conditions resulted in a three-fold increase in TTHM and 30% increase in HAA5.

As with the organic DBP, instantaneous samples were collected for the feed and treated water inorganic DBP analyses. The promulgated Disinfectant/Disinfectant Byproduct Rule (D/DBPR) has an MCL of 0.8 mg/l for chlorite. Chlorite was not detected in either sample. Chlorate was detected in both the feed water and treated water. SDS conditions resulted in a doubling of the instantaneous chlorate level to 0.262 mg/l. There are presently no proposed regulations for chlorate.

Another disinfectant byproduct of ongoing concern using on-site generation of sodium hypochlorite is bromate. Bromate will be regulated under Stage 1 of the D/DBPR with an MCL of 0.01 mg/L. Although bromate was not a parameter required to be analyzed under the NSF on-site halogen production protocol, the precursor of bromate (bromide) was a required analysis. No bromide was detected in either the feed water or treated water. Bromide was also not detected in the chemical analysis of the sodium chloride used during the testing.

Feed Stock Consumption

Feed stock consisted of a solar grade salt and softened water used to dilute the salt into a brine solution. The salt is certified to be 99% pure sodium chloride, and contains a calcium concentration of less than 0.23%. The calcium concentration is important due to the scaling effect it can have on the generator electrode plates. Over the course of the 30 day test period, an average of 247 pounds of salt were used on a daily basis, producing an average of 842 gpd of 0.9% sodium hypochlorite.

Power Consumption

Power consumption was recorded daily for voltage and amperage, which was displayed locally on the power supply/rectifier, and remotely on the PLC cabinet LCD screen. The average daily DC current and voltage applied to the electrolytic cells was 183 amps and 46 volts, respectively.

Maintenance

There were a few items that required maintenance during the ETV, none of which directly involved the ClorTec MC 100 system but rather the softener, pump feed line and pH meter.

The hypochlorite generator electrodes had started to develop a scale formation by the end of the 30-day test, although the scaling had not developed to the point of loss in generator efficiency, requiring acid cleaning. (A loss in generator efficiency becomes evident when an increase in power is required to maintain the same level of concentrated chlorine).

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E. Timothy Oppelt Date
Director
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Tom Bruursema *10/13/00*

Tom Bruursema Date
General Manager
Environmental and Research Services
NSF International

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 #00/16/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)

September 2000

Environmental Technology Verification Report

On-Site Sodium Hypochlorite Generation System Used for Disinfection in Drinking Water

ClorTec, a Division of Capital Controls
Model MC 100 On-Site Sodium Hypochlorite Generation System

Prepared for:

NSF International
Ann Arbor, Michigan 48105

Prepared by:

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Under a Cooperative Agreement with the U.S. Environmental Protection Agency

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Notice

The U.S. Environmental Protection Agency (EPA) through its Office of Research and Development has financially supported and collaborated with NSF International (NSF) under Cooperative Agreement No. CR 824815. This verification effort was supported by Drinking Water Treatment Systems Pilot operating under the Environmental Technology Verification (ETV) Program. This document has been peer reviewed and reviewed by NSF and EPA and recommended for public release.

Foreword

The following is the final report on an Environmental Technology Verification (ETV) test performed for the NSF International (NSF) and the United States Environmental Protection Agency (EPA) by Gannett Fleming, Inc., in cooperation with ClorTec, a division of Capital Controls. The test was conducted during March 8 through April 6, 2000 at the Hummelstown Water Treatment Plant (WTP), Hummelstown, Pennsylvania.

Throughout its history, the EPA has evaluated the effectiveness of innovative technologies to protect human health and the environment. A new EPA program, the Environmental Technology Verification Program (ETV) has been instituted to verify the performance of innovative technical solutions to environmental pollution or human health threats. ETV was created to substantially accelerate the entrance of new environmental technologies into the domestic and international marketplace. Verifiable, high quality data on the performance of new technologies are made available to regulators, developers, consulting engineers, and those in the public health and environmental protection industries. This encourages more rapid availability of approaches to better protect the environment.

The EPA has partnered with NSF, an independent, not-for-profit testing and certification organization dedicated to public health, safety and protection of the environment to verify performance of small package drinking water systems that serve small communities under the ETV Drinking Water Treatment Systems (DWTS) Pilot Project. A goal of verification testing is to enhance and facilitate the acceptance of small package drinking water treatment equipment by state drinking water regulatory officials and consulting engineers while reducing the need for testing of equipment at each location where the equipment's use is contemplated. NSF will meet this goal by working with manufacturers and NSF-qualified Field Testing Organizations (FTO) to conduct verification testing under the approved protocols.

The ETV DWTS is being conducted by NSF with participation of manufacturers, under the sponsorship of the EPA Office of Research and Development, National Risk Management Research Laboratory, Water Supply and Water Resources Division, Cincinnati, Ohio. It is important to note that verification of the equipment does not mean that the equipment is "certified" by NSF or "accepted" by EPA. Rather, it recognizes that the performance of the equipment has been determined and verified by these organizations for those conditions tested by the FTO.

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Abbreviations and Acronyms

A	Amp
AC	Alternating Current
ANOVA	Analysis of Variance
CAAA	Clean Air Act Amendment
$CaCO_3$	Calcium Carbonate
CFU	Colony Forming Unit
Cl	Chlorine
cm	Centimeter
EC	Degrees Celsius
C.U.	Platinum-Cobalt Color Units
D	Depth
DBP	Disinfectant Byproduct
DBPFT	Disinfectant Byproduct Formation Testing
DC	Direct Current
EPA	Environmental Protection Agency
ETV	Environmental Technology Verification
°F	Degrees Fahrenheit
FAC	Free Available Chlorine
FRP	Fiberglass Reinforced Plastic
FOD	Field Operations Document
FTO	Field Testing Organization
gph	Gallons Per Hour
gpd	Gallons Per Day
gpm	Gallons Per Minute
H	Height
HAA5	Haloacetic Acids-5
HazMat	Hazardous Material
HCl	Hydrochloric Acid
HDPE	High Density Polyethylene
HPC	Heterotrophic Plate Count
HP	Horsepower
HZ	Hertz
ICR	Information Collection Rule
kWh	Kilowatt-hours
L	Liter
lb	Pound
LCD	Liquid Crystal Diode
LED	Liquid Emitting Diode
M	Mole
mA	milliAmp
MCL	Maximum Contaminant Level
mg/l	Milligram per Liter
ml	Milliliter
MPN	Most Probable Number
MSDS	Material Safety Data Sheets

NA	Not Analyzed
NaCl	Sodium Chloride
NaOCl	Sodium Hypochlorite
NaOH	Sodium Hydroxide
NEMA	National Electrical Manufacturers Association
NH_3-N	Ammonia Nitrogen
NIST	National Institute of Standards and Technology
NOM	Natural Organic Matter
NPDES	National Pollution Discharge Elimination System
NR	Not Reported
NSF	NSF International (formerly known as National Sanitation Foundation)
NSR	No Softener Regeneration
NT	Not Tested
NTU	Nephlometric Turbidity Units
OIT	Operator Interface Terminal
O&M	Operation and Maintenance
OSHA	Occupational Safety and Health Administration
PADEP	Pennsylvania Department of Environmental Protection
PE	Professional Engineer
PLC	Programmable Logic Controller
PRV	Pressure Reducing Valve
PSM	Process Safety Management
PSI	Pounds per Square Inch
PVC	Poly Vinyl Chloride
QA/QC	Quality Assurance/Quality Control
QAPP	Quality Assurance Project Plan
RMP	Risk Management Plan
SCR	Speed Control Rheostat
SDS	Simulated Distribution System
SHG	Sodium Hypochlorite Generation
SM	*Standard Methods*
SS	Stainless Steel
TAC	Total Available Chlorine
TC	Total Coliform
TDS	Total Dissolved Solids
TOC	Total Organic Carbon
TTHM	Total Trihalomethane
UFC	Uniform Formation Conditions
UPS	Uninterruptible Power Supply
UVA	Ultraviolet Absorbance
UV_{254}	Ultraviolet Absorbance @ 254 nanometers
μg/l	microgram per liter
V	Volts
VDC	Volts Direct Current
VAC	Volts Alternating Current
W	Width
WTP	Water Treatment Plant

Acknowledgements

The Field Testing Organization, Gannett Fleming, Inc., was responsible for all elements in the testing sequence, including collection of samples, calibration and verification of instruments, data collection and analysis, data management, data interpretation and the preparation of this report.

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The laboratory selected for microbiological analysis and non-microbiological analytical work of this study was:

Microbac Laboratories, Inc.
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The Manufacturer of the Equipment was:

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Gannett Fleming, Inc., wishes to thank the following participants:

NSF International, especially Bruce Bartley, Project Manager, and Carol Becker, Environmental Engineer, for providing guidance and program management.

The United Water Pennsylvania staff including Timothy K. McGarvey, Production Superintendent; Rob Roth, Water Quality Manager; and Ron Artley, Assistant Production Superintendent; provided operator training assistance and technical guidance. Dale Garrett, George Hawthorne, Bill Reynolds, Tami Wilson, Bob Heineman, Matt Hobba and Phil Barley, WTP operators, provided on-site monitoring, data collection and analytical assistance.

Greg Cibinski, Director of Engineering, for ClorTec, and Chester Parks, Sales Engineer of CP Equipment Sales Company, provided technical and product expertise.

Chapter 1
Introduction

1.1 ETV Purpose and Program Operation

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.

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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 evaluated the performance of the ClorTec Model MC 100 system, which is an on-site sodium hypochlorite generation (SHG) system used in package drinking water treatment system applications. The performance claim evaluated during field testing of the system was that the system is capable of producing sodium hypochlorite at a concentration of 0.8% ± 0.05%, from 99.7% purity sodium chloride in 3.0% solution. This document provides the verification test results for the ClorTec Model MC 100 system.

1.2 Testing Participants and Responsibilities

The ETV testing of the ClorTec Model MC 100 system was a cooperative effort between the following participants:

NSF International
Gannett Fleming, Inc.
ClorTec, a Division of Capital Controls (ClorTec)
United Water Pennsylvania
U.S. Environmental Protection Agency
Microbac Laboratories, Inc.

The following is a brief description of each ETV participant and their roles and responsibilities.

1.2.1 NSF International

NSF is a not-for-profit testing and certification organization dedicated to public health safety and the protection of the environment. Founded in 1946 and located in Ann Arbor, Michigan, NSF has been instrumental in the development of consensus standards for the protection of public health and the environment. NSF also provides testing and certification services to ensure that products bearing the NSF Name, Logo and/or Mark meet those standards. The EPA partnered with the NSF to verify the performance of drinking water treatment systems through the EPA's ETV Program.

NSF provided technical oversight of the verification testing. An inspection of the field analytical and data gathering and recording procedures was conducted by NSF. NSF also provided review of the Field Operations Document (FOD) and this report.

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1.2.2 Field Testing Organization

Gannett Fleming, Inc., a consulting engineering company, conducted the verification testing of the ClorTec Model MC 100 system. Gannett Fleming, Inc., is an NSF-qualified Field Testing Organization (FTO) for the ETV Drinking Water Treatment Systems pilot project.

The FTO was responsible for conducting the verification testing for 30 calendar days. The FTO provided all needed logistical support, established a communications network, and scheduled and coordinated activities of all participants. The FTO was responsible for ensuring that the testing location and feed water conditions were such that the verification testing could meet its stated objectives. The FTO prepared the FOD, oversaw the pilot testing, managed, evaluated, interpreted and reported on the data generated by the testing, as well as evaluated and reported on the performance of the technology.

United Water Pennsylvania employees conducted the on-site analyses and data recording during the testing. Oversight of the daily tests was provided by the FTO's Project Engineer and Project Manager.

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1.2.3 Manufacturer

The treatment system is manufactured by ClorTec, a manufacturer of alternative chlorine technologies for the municipal and industrial water and wastewater markets.

The manufacturer was responsible for supplying a field-ready on-site SHG system equipped with all necessary components including treatment equipment, instrumentation and controls, and an operations and maintenance manual. The manufacturer was responsible for providing logistical and technical support as needed as well as providing technical assistance to the FTO during operation and monitoring of the equipment undergoing field verification testing.

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Contact Person: Greg Cibinski, Director of Engineering
Email: **Greg@ClorTec.com**

1.2.4 Analytical Laboratory

Full service environmental laboratory services were provided by Microbac Laboratories, Inc. Microbac Laboratories is certified in the State of Pennsylvania for drinking water quality analyses (PA DEP Certification No. 21-133).

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Contact Person: Cheri Casari, Laboratory Manager
Email: **ccasari@gfnet.com**

1.2.5 U.S. Environmental Protection Agency

The EPA through its Office of Research and Development has financially supported and collaborated with NSF under Cooperative Agreement No. CR 824815. This verification effort was supported by the Drinking Water Treatment Systems Pilot operating under the ETV Program. This document has been peer reviewed and reviewed by NSF and EPA and recommended for public release.

1.2.6 United Water Pennsylvania

The public water supplier United Water Pennsylvania provided staffing for monitoring, data collection and on-site water quality analyses for the ETV.

1.3 Verification Testing Site

The site selected for the verification testing is a surface water treatment plant (WTP) located within the Borough of Hummelstown, approximately five miles east of Harrisburg, Pennsylvania. The treatment plant, known as the Hummelstown WTP, is owned and operated by United Water Pennsylvania. The main building of the treatment plant dates to the late 19^{th} century, and was at one time a power generation station for the Borough. The chemical feed room in this building is the location of the on-site SHG system. What is now WTP process wastewater lagoons was originally a sluice for providing water to power a water wheel (since removed) located inside the building. Since converting the building to a WTP additional facilities have been added, including a filter building, clarifier and two finished water storage tanks. The most recent addition, in November/December 1999, was the ClorTec Model MC 100 system.

1.3.1 Source Water and Existing Treatment

The treatment plant withdraws water from the adjacent Swatara Creek, its only source of supply. The Swatara Creek Watershed encompasses an area of 483 square miles of primarily rural flatlands consisting of mixed agricultural and wooded areas.

The water is pumped directly from Swatara Creek to the treatment plant, where pretreatment chemicals (sodium hypochlorite, lime, and alum) are fed just prior to an in-line rapid mixer. Following rapid mixing, the coagulated water flows to a solids contact clarifier for flocculation and clarification. Clarified water flows to a set of four conventional dual media filters containing anthracite and sand. The combined flow of the four filter effluents is chlorinated with sodium hypochlorite prior to flowing to two above-ground finished water storage tanks.

The ClorTec Model MC 100 system is the source of chlorine for both pre and post chlorine at the treatment plant, and both pre and post chlorine were fed during the verification test. However, for ETV monitoring purposes, the post chlorine feed point was selected as the equipment verification testing location. Therefore, all sample locations designated as feed water during the ETV were from the combined filter effluent upstream of the post chlorine feed point. All feed water monitoring samples were collected from a filter effluent sample pump located in the filter building. The treated water monitoring samples were collected from the sample sink located in the WTP operators lab. This water is a side stream of the water pumped from the finished water storage tanks, and therefore has undergone post chlorination and contact time prior to monitoring.

The summary of the feed water quality information is presented in Table 1-1.

Table 1-1. Feed Water Quality

	Total Alkalinity (mg/l)	Temperature (°C)	pH	TDS[1] (mg/l)	FAC (mg/l)	Total Coliform (mpn/100 ml)	HPC (cfu/100 ml)	True Color (C.U.)	UV_{254} (cm^{-1})	Ammonia (mg NH_3-N/l)	Turbidity bench (NTU)
Mean	28	11.4	7.00	139	0.36	<1	4	5	0.021	<0.10	0.067
Minimum	15	7.5	6.20	139	0.01	<1	0	5	0.017	<0.10	0.040
Maximum	37	15.1	7.60	139	1.38	<1	73	5	0.023	<0.10	0.100
Standard Deviation	11	1.9	0.32	0	0.24	0	16.5	0	0.003	0	0.017
95% Confidence Interval	28 ± 10.4	11.4 ± 0.7	7.00 ± 0.12	N/A	0.36 ± 0.06	N/A	4 ± 7.6	N/A	0.021 ± 0.003	N/A	0.067 ± 0.006

(1) One Analysis
"<1" was assigned a zero value for the purposes of calculating an average and standard deviation.
N/A = Not Applicable because standard deviation = 0.

1.3.2 Treated Water Discharge

The ClorTec Model MC 100 system at the treatment plant is a permanent installation that has been granted an operating permit by the Pennsylvania Department of Environmental Protection (PADEP) to treat raw and finished water. As such, there is no treated water discharge from the on-site SHG. The softener regenerant wastewater flows to the WTP process wastewater lagoons.

1.3.3 Installation and Start-up

The SHG equipment was installed and started up (run to waste) in December of 1999. Following the receipt of an operating permit from the PADEP in January of 2000, the SHG equipment was placed on-line, replacing pre and post gas chlorinators as the source of chlorine. An initial operations period spanning several months prior to the initiation of the ETV allowed United Water Pennsylvania staff to optimize the equipment's operations and add system appurtenances as required for the site-specific characteristics. In addition, initial operations provided "hands-on" training for the WTP operators. Set points were established and entered into the PLC for parameters such as high and low tank levels, which enabled automation of the batch system operating mode.

It was determined during this period of operations that if the brine dilution water temperature dropped much below 50°F, a sodium hypochlorite concentration of 0.8% was not attainable regardless how much the amperage and voltage settings were increased within the power supply/rectifier's range. Subsequently, United Water Pennsylvania staff installed an in-line water heater that maintains an adjustable minimum dilution water temperature; the temperature is monitored upstream and downstream of the in-line heater with in-line thermometers. This has resolved the "cold dilution water" problem, enabling the SHG system to always have the capacity of producing an 0.8% concentration of sodium hypochlorite within the rectifier power supply's range.

Chapter 2
Equipment Description and Operating Processes

2.1 Equipment Description

The equipment tested was the ClorTec Model MC 100 system. This system is designed to produce a 0.8% sodium hypochlorite solution from a 3% sodium chloride solution using an applied low voltage DC current. The actual concentration of sodium hypochlorite solution generated is dependent on the temperature and salt concentration of the brine solution, and the amperage and voltage applied.

The ClorTec Model MC 100 system is designed to produce up to 100 pounds per day (lbs/day) of sodium hypochlorite as chlorine. The system configuration is modular and consists of three major components: rack-mounted sodium hypochlorite generator; control cabinet, which houses the programmable logic controller (PLC) and operator interface terminal (OIT); and power supply/rectifier. In addition, a brine generation and storage system supplies the feedstock for the generator. Figure 2-1 presents a schematic of the ClorTec Model MC 100 system and appurtenances. The major components are described in more detail in the following sections.

2.1.1 Brine Generation and Storage System

The brine solution used for generating sodium hypochlorite is prepared using several stages of dilution.

2.1.1.1 Softener

ClorTec requires that all brine dilution water be softened to remove minerals that may cause scaling on the electrolytic plates. The following equipment produced softened water for the ClorTec Model MC 100 system.

- Two Kinetico Model No. 60 ion exchange modules
  - each module is rated for 8.0 gallons per minute (gpm) service flow
  - maximum pressure drop: 15 pounds per square inch (psi)
  - ion exchange capacity: 3772 grains of hardness per lb of salt
  - useable gallons between regenerations: 1,200

2.1.1.2 Cartridge Filters

Cartridge filtration is recommended by ClorTec to prevent debris from fouling downstream solenoid valves and the brine pump poppet valves. One cartidge filter is located just downstream of the softener; the other cartridge filter is located just upstream of the brine day tank influent.

- Cartridge filter porosity: 25 µm

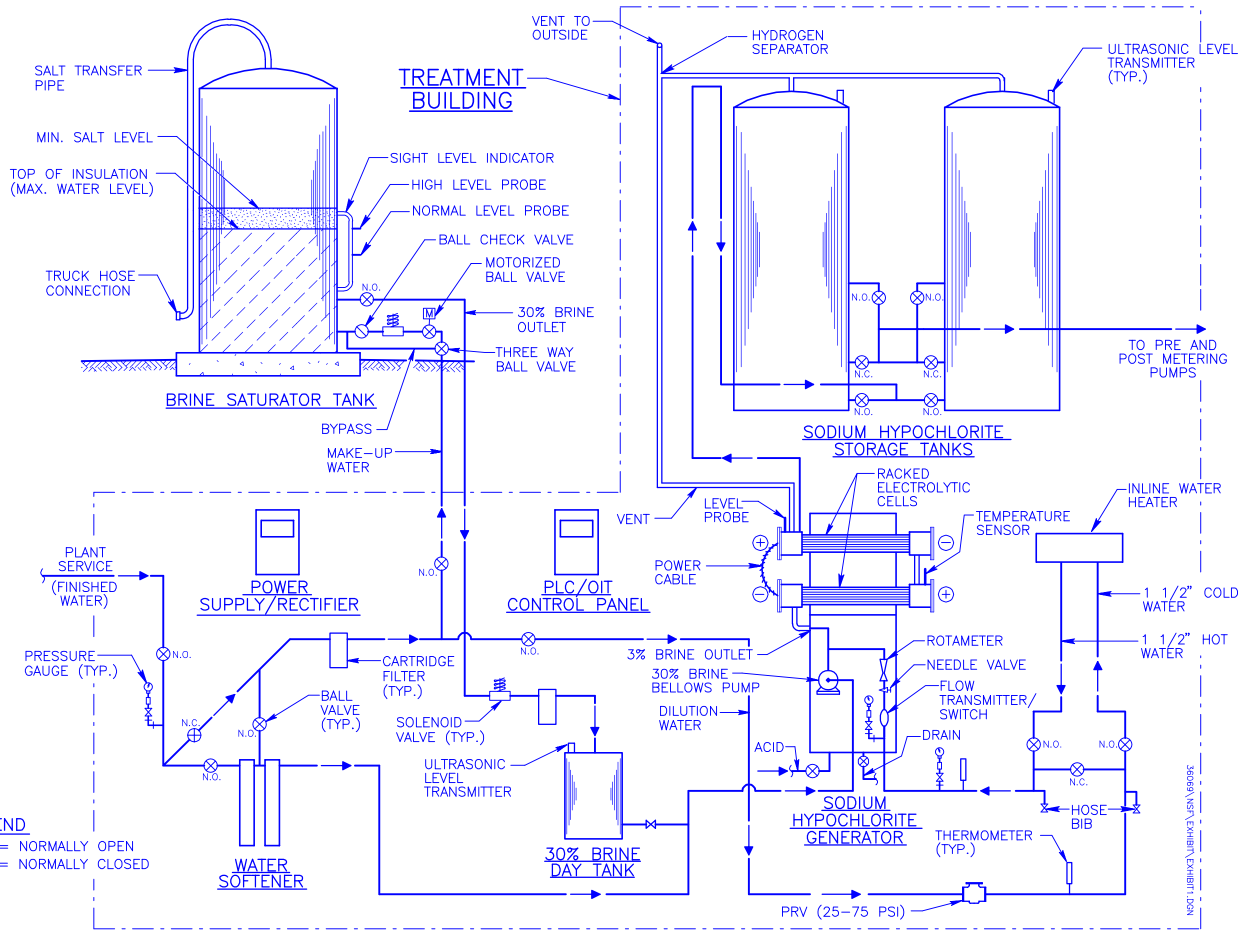


Figure 2-1 Schematic of Clortec Model MC100 Sodium Hypochlorite Generation System and Appurtenances at United Water PA- Hummelstown WTP

LEGEND

N.O. = NORMALLY OPEN

N.C. = NORMALLY CLOSED

2.1.1.3 Brine Bulk Saturator Tank

The brine bulk saturator tank, which appears in Photograph 2.1, functions to generate and store 30% brine solution.

- The tank, Beden-Baugh Products Inc. Brinemaster Salt Dissolver, has the following specifications and appurtenances
    - 40 ton salt capacity
    - side shell - 16 ft
    - diameter - 10 ft
    - covered fiberglass reinforced plastic (FRP) tank with 72H resin interior corrosion barrier
    - 1.5 inch thick urethane insulation (bottom six feet of tank)
    - 75 feet of heat tracing under insulation (Accutron CW-6, temperature setting 50^{o}F, 120 VAC)
    - brine sight level indicator
    - high/normal brine level probes with output signal to PLC
    - motorized ball valve and solenoid valve controlled by PLC (make-up water pipe)
    - two inch salt transfer pipe

Photograph 2.1
Brine Bulk Saturator Tank

2.1.1.4 Brine Day Tank

One brine day tank serves as the primary supply of 30% brine for the SHG following transfer from the saturator tank. The day tank has the following specifications and appurtenances:

- 55 gallon high density polyethylene (HDPE) tank
- tank equipped with ultrasonic level transmitter (Flowline Model LU20) with output signal to PLC for control of brine supply from saturator tank

2.1.1.5 Sodium Hypochlorite Storage Tanks

The following tanks and appurtenances store the on-site generated sodium hypochlorite:

- two 1,400 gallon HDPE tanks
- each tank is equipped with an ultrasonic level transmitter (Flowline Model LU20) with output signal to PLC for control of generator batch operation

2.1.2 Sodium Hypochlorite Generator System

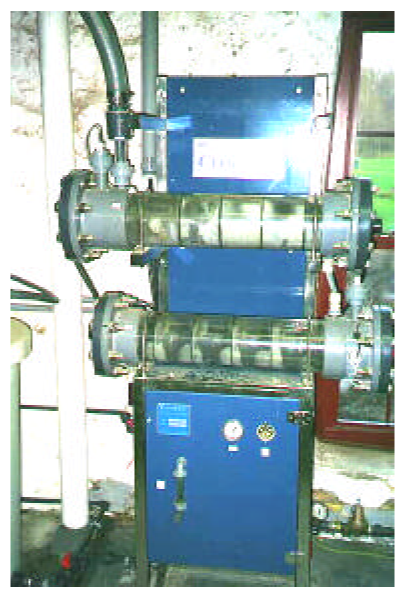
The ClorTec Model MC 100 system consists of two electrolytic cells racked horizontally on top of a steel cabinet which houses one bellows-type brine pump, one solenoid valve, and one junction box. Mounted on the outside of the cabinet are one flow indicator/transmitter and flow switch, one rotameter and flow control valve, and one pressure gauge.

System specifications are as follows:

Photograph 2.2
Softener, PLC, Brine Day Tank and Hypochlorite Generator

- Output – 100 lb/day (as chlorine)
- Flow – 62.5 gallons per hour (gph) (sodium hypochlorite)
- Electrolytic Cells – two @ 50 lb/day production capacity each (as chlorine)
- Pressure Range – 30 psi to 70 psi
- Water consumption – 1,500 gallons per day (gpd)
- Salt consumption – 350 lb/day
- Power consumption – 250 kilowatt-hours (kWh)/day alternating current (AC)
- Required power supply – 480 volts (V), 3 phase
- Current draw – 16 amps AC
- Required circuit rating – 30 amps (A)
- Cabinet dimensions – 24 inch width (W) x 18 inch depth (D) x 72 inches height (H).

2.1.2.1 Electrolytic Cells



Photograph 2.3
Sodium Hypochlorite Generator

Each electrolytic cell consists of a 4 inch diameter clear polyvinyl chloride (PVC) tube that contains an array of ten pairs of flat-plate anode and cathode electrodes that are uniformly spaced approximately 1/4 inch apart. The clear tube allows for viewing the process and the electrode condition. The cylindrical design permits access to the electrode array, which can be removed as a single unit. Maximizing the surface area of the plates lowers current density, resulting in longer electrode life and lower cell temperature. The electrodes are made of titanium with proprietary metal oxide and catalytic precious metal coatings (ruthenium, iridium, platinum) for electrical efficiency and longevity. Brine solution flows through the plates where it is subjected to a low voltage direct current (VDC) to produce sodium hypochlorite and the only byproduct, hydrogen. The cells are designed for rapid hydrogen separation to produce maximum gas lift at the electrode surface and minimize calcification of the electrodes. The cells are in series electrically and hydraulically, so that Cell No. 1 discharges to Cell No. 2. Hydrogen is vented from the effluent end of Cell No. 2 via a two-inch diameter flexible hose connected to a PVC pipe which discharges outside the building.

There are two safety devices to protect the electrolytic cells: (1) a level transmitter monitors the top cell's liquid level, which must be above the electrodes; and (2) a temperature transmitter monitors the lower cell's temperature, which must be below 122 degrees Fahrenheit (°F). If either of these parameters is outside its specified limit, the PLC will shut down the system.

There are three PVC ball valves with barbed tube connections at the base of the cabinet: 1) brine influent feed, 2) acid influent feed, and 3) electrolytic cell drainage.

2.1.2.2 Brine Dilution System

The generator cabinet houses a bellows-type pump that is factory set to deliver the 30% brine at a flow rate of 0.1 gpm from the day tank to the dilution water blending tee located inside the generator cabinet. Prior to blending, the softened dilution water is filtered through a 25 micron cartridge filter, followed by pressure reduction from approximately 80 psi to 60 psi through a pressure reducing valve (PRV). Prior to entering the SHG cabinet, the dilution water is heated, as required, with an in-line heater (Controlled Energy Corp., 9500 watts, 240 volts) to maintain a temperature above 50^{o} F. The dilution water is then blended with the 30% brine at a flow rate of 1.0 gpm dilution water to 0.1 gpm of brine to develop an approximate 3.0% brine solution.

Three gauges are mounted on the front of the generator cabinet. Two gauges monitor dilution water flow (a flow indicator/transmitter and a rotameter with needle valve), and one gauge monitors dilution water pressure.

2.1.3 PLC/OIT Control Cabinet

The control cabinet consists of a 316 stainless steel (SS), National Electrical Manufacturers Association (NEMA) 4X cabinet that houses all control and display functions for the SHG system. Logic functions are at the PLC level where operating parameters are monitored, corrected, scaled, reported, and controlled.

A PLC controller monitors and controls each aspect of the system's operation, including:

- Cell Safety Devices
- Rectifier Controls
- DC Amperage and Voltage
- Brine Bulk Saturator and Day Tank Levels
- Sodium Hypochlorite Storage Tank Levels
- Alarm Reset
- Alarm History
- Security Protection
- Hypochlorite Metering Pump Flow Pacing and Measuring
- Salt Usage Log
- Maintenance Log

The PLC has trending capability for five operating parameters:

- Sodium Hypochlorite Storage Tank Level

- Dilution Water Flow Rate
- Chlorine Residual
- Rectifier Amperage
- Rectifier Voltage

The control cabinet also includes an OIT. The OIT provides the following functions:

- Operator Interface
- Alarm Viewer
- Communications Hub
- Data Input Screen

The OIT includes a touch sensitive screen to allow menu scrolling, selection and data entry.

The control system includes safety interlocks that will prevent SHG operation if any of the following operating parameters fall outside their specified limits:

- Dilution water flow
- Cell high temperature
- Cell low level
- Transformer high temperature
- Cell over-voltage
- Automatic voltage and current regulation
- Hypochlorite storage tank high level

The control system will generate an alarm but will not shut down the SHG system on hypochlorite storage tank low level.

An uninterruptible power supply (UPS) is housed in the control cabinet to provide constant power to the PLC so that any fluctuations or brief losses of AC power will not affect the system's controls. The UPS will provide constant power to the PLC for 15 minutes after complete loss of 120 VAC power.

2.1.4 Power Supply/Rectifier

The rectifier provides constant current to the electrolytic cells within specified voltage ranges. Rectifier operation is entirely controlled by the PLC. The rectifier has the following features:

- 150 Amp Speed Control Rheostat (SCR) Thyristors
- Class H Insulation
- NEMA 1 Enclosure
- Frame Mounted
- PVC Enclosed
- Air Cooled

Photograph 2.4
Power Supply/Rectifier

- Emergency Stop
- DC Amp and Volt meters
- 3 Phase Motor Starter
- 4-20 milliAmp (mA) output of Volts and Amps
- Phase Monitoring
- Power and Fault Light
- 480 V Disconnect

The rectifier is compatible with all capacities of the ClorTec series of SHG systems. It has a voltage range of 25 to 75 volts DC @ 180 amps.

2.2 Equipment Operations

2.2.1 Brine Generation and Storage System

Salt is conveyed to the brine bulk saturator tank by pneumatic transfer from a delivery truck via a truck hose connection through a transfer pipe into the top of the tank. A 30% brine solution is produced in the brine bulk saturator tank by dissolving a solar grade of sodium chloride (that meets all specifications in ANSI/AWWA Standard B200-98) with WTP finished water that has undergone softening and cartridge filtration. The brine level in the saturator tank is maintained below the salt, which assures that a 30% brine concentration is maintained (approximate solubility of sodium chloride above 50°F is 30%). A two level probe system maintains the brine depth in the tank within a range set at the PLC by controlling the operation of a solenoid valve on the softened water supply.

The thermostatically controlled electric heat tracing together with insulation around the bottom six feet of the tank maintain a minimum water temperature inside the tank of 50^{o}F.

An ion exchange softener treats all of the dilution water supplied to the brine saturator tank. The softener automatically cycles into backwash, regeneration and rinse following the treatment of an adjustable preset volume of water.

Brine levels in the brine day tank are measured by an ultrasonic level transmitter mounted on the top of the tank. Refilling of the day tank occurs automatically; a solenoid valve on the discharge pipe between the saturator tank and the day tank is controlled by adjustable high and low level day tank settings in the PLC. When the brine depth drops to the low level setting, the solenoid valve receives a signal to open, allowing the day tank to fill. When the brine fills to the high level setting, the PLC controller sends a signal to the solenoid valve to close.

2.2.2 Sodium Hypochlorite Generator System

As stated previously, the 30% brine solution is blended with softened plant treated water at a ratio of 1:10 (0.1 gpm brine to 1.0 gpm softened water) to produce a brine solution that is approximately 3% in strength. After dilution, the 3% brine flows through two electrolytic cells in series where a low voltage DC current from the rectifier is applied to generate approximately

0.8% sodium hypochlorite, with hydrogen gas as a byproduct. The hydrogen is safely vented outside the building via a two inch PVC pipe.

The SHG system operates in automatic batch mode, activated from a standby mode whenever the level in either one or both of the sodium hypochlorite storage tanks reaches the adjustable low level setting in the PLC, based on the tanks' ultrasonic level transmitter readings. The generator will continue to operate until the sodium hypochlorite level in the storage tanks rises to the PLC adjustable high level setting, as reported by the ultrasonic level transmitters. A flow indicator/transmitter on the softened dilution water line sends a signal to the PLC, which will shut down the generator if dilution water flow is out of range of parameter set points.

The electrolytic cells have two transmitters: one transmitter monitors temperature to protect the electrodes from temperatures above 122^{o}F; the other transmitter monitors the sodium hypochlorite level to prevent exposure of the electrodes. Based on settings in the PLC, the system will be shutdown if either of these conditions occur.

2.2.2.1 Cell Electrode Cleaning

When scaling on the electrodes results in not being able to generate approximately 0.8% sodium hypochlorite within the specified voltage range, the generator should be taken off line for cleaning. A weak acid such as muriatic acid is used for removing the scaling. The operator should have eye and body protection in place before starting the cleaning procedure. The procedure as presented in the *MC Operator Interface PLC Manual* is as follows:

1. Turn off the rectifier's disconnect
2. Drain the cells
3. Flush the cells with water by first closing the brine needle valve on the generator cabinet, followed by filling the cells using the priming mode on the PLC to prime the bellows pump (the cells should be filled and emptied a minimum of three times before starting the acid wash)
4. Close the brine valve and open the acid valve on the generator cabinet
5. Connect a piece of 3/8 inch ID tubing to the acid tubing barb and place the other end of the 3/8 inch tube into a one gallon container of the acid solution
6. Press Start on the PLC and the cell will begin to fill with the acid solution
7. Allow the cells to fill in priming mode to the top cell. Once the acid solution fills the top cell, press Stop
8. If the cells are not cleaned, drain them and repeat the previous steps as necessary
9. Once the cells are clean, drain the solution
10. Flush the cell by repeating Step 4 with softened dilution water instead of acid
11. After flushing three times, open the brine valve and begin priming the cell
12. Once primed, turn on the rectifier disconnect
13. Press Start and the ClorTec system is back in production
14. Confirm proper voltage on the rectifier

2.2.3 PLC/OIT

The PLC-based control system monitors and controls each aspect of the ClorTec Model MC 100 system's operation by processing and reporting operating parameters including process flow, tank levels, system status and alarm conditions.

The OIT provides the plant operator the capability to access system control settings, view alarms, and review trending of operations data previously logged.

2.2.4 Power Supply/Rectifier

The rectifier converts AC current to DC current and applies it at a constant rate to the electrolytic cells within a specified voltage range. The operation is completely controlled by the PLC.

2.3 Advantages and Disadvantages

2.3.1 Advantages of On-Site Sodium Hypochlorite Generation

2.3.1.1 Comparison of On-Site SHG and Commercially Available Sodium Hypochlorite (12% to 15%)

- Stability of sodium hypochlorite is dependent on the following: hypochlorite concentration, storage temperature, time in storage, impurities in solution and exposure to light. Decomposition of sodium hypochlorite affects dosage and feed rate, and the production of undesirable byproducts such as chlorate ions. Commercially available sodium hypochlorite is more susceptible to decomposition than on-site SHG. Twelve percent sodium hypochlorite stored for approximately 30 days under the best conditions will degrade to ten percent. Since SHG is used almost immediately, it does not have the opportunity to degrade.
- Commercially available sodium hypochlorite has a pH of 13; on-site SHG has a pH of 9, and is therefore less likely to cause scaling of feed lines and fittings.
- Storage area requirements are reduced for SHG due to "on-demand" production.
- SHG, due to its low chlorine concentration, does not have the containment requirements of commercially available sodium hypochlorite.
- Occupational Safety and Health Adminstration (OSHA) Process Safety Management (PSM) is not required for SHG; commercially available sodium hypochlorite requires PSM.

2.3.1.2 Comparison of On-Site SHG and Gas Chlorine

- Chlorine gas requires the handling of 150 lb. chlorine cylinders or ton containers; SHG does not require handling of any containers.
- EPA Risk Management Plan (RMP) or OSHA Process Safety Management PSM is not required for SHG; Chlorine gas requires EPA RMP and OSHA PSM.

- Chlorine gas requires isolated containment of its storage and feed facilities; SHG storage and feed facilities can be located in a common room with other equipment.
- SHG does not have scrubber requirements, as is required with most gas chlorine installations. Scrubbing for accidental leak remediation is mandated by the Uniform Fire Code (Article 80) and EPA's Clean Air Act Amendment (CAAA) Title III.
- Chlorine gas, at a $pH < 1$, can have a significant impact on the treated water pH; SHG, at a $pH = 9$, has little, if any, impact on treated water quality.

2.3.2 Disadvantages of On-Site SHG

- Higher electrical power required for SHG than chlorine gas or commercially available sodium hypochlorite.
- Larger capacity metering pumps required for SHG than for commercially available sodium hypochlorite.
- Dilution water softening and minimum temperature is requirements for SHG.
- Production of hydrogen gas byproduct presents a potential explosive condition if the SHG system is not properly designed for off-gas.
- Cell descaling is periodically required for SHG.
- Softener brine wastewater disposal is required for SHG.
- Cost of electrode replacement is a consideration for SHG, but not chlorine gas or commercially available sodium hypochlorite.
- SHG storage area requirements, although less than for commercially available sodium hypochlorite, are greater than for chlorine gas.

Chapter 3
Methods and Procedures

3.1 Experimental Design

The experimental design of this verification study was developed to provide accurate information regarding the performance of the ClorTec Model MC 100 system. Field operations, sampling, and analytical methodologies were standardized as much as possible to validate collected data.

3.1.1 Objectives

The objectives of this verification testing were to evaluate the performance of ClorTec Model MC 100 system, specifically relative to ClorTec's stated equipment performance claim and relative to regulatory requirements. Impacts of feed water quality variations, operational requirements and maintenance requirements were also evaluated. The details of these evaluations are presented below.

3.1.1.1 Evaluation of Stated Equipment Performance Claim

ClorTec's stated performance claim was in terms of the concentration of sodium hypochlorite generated. ClorTec claims their Model MC 100 system is capable of producing sodium hypochlorite at a concentration of 0.8% ± 0.05% as chlorine, from a 3% brine solution containing 99.7% pure sodium chloride. Evaluation of this claim was performed by conducting twice daily analyses of the concentrated sodium hypochlorite generator stream using two different analytical methods for total chlorine analysis. Once daily monitoring of the actual sodium chloride concentration was conducted by measuring the specific gravity of the dilute brine solution.

3.1.1.2 Evaluation of Performance Relative to the EPA Safe Drinking Water Regulations

The sodium hypochlorite generated on-site was evaluated in terms of its effectiveness for inactivating Total Coliform and Heterotrophic Plate Counts. It was also evaluated for adequacy of maintaining a chlorine residual in the WTP finished water storage tanks sufficient to achieve 1.0 log inactivation of *Giardia* cysts post filtration (EPA, 1989). Disinfectant byproducts that have been selected for regulation under Stage 1 of the promulgated Disinfectant/Disinfectant Byproduct Rule (D/DBPR) were analyzed to get a "snapshot" of disinfectant byproduct levels using on-site SHG.

3.1.1.3 Evaluation of Equipment Performance Relative to Feed Water Quality

Water quality upstream of the post sodium hypochlorite feed point was evaluated relative to the water quality downstream of this feed point to determine the impact of sodium hypochlorite addition as a chlorine residual disinfectant. Other than chlorine residual, water quality upstream and downstream of the feed point was not anticipated to vary significantly. A range of feed and treated water quality parameters were analyzed at a frequency varying from twice daily to once per test period.

3.1.1.4 Evaluation of Operational Requirements

An overall evaluation of the operational requirements for the treatment system was undertaken as part of this verification. The *ClorTec's Operater Interface PLC Manual* (O&M), and experiences during the daily operations, were used to develop a subjective evaluation of the operational requirements of the system.

3.1.1.5 Evaluation of Maintenance Requirements

ClorTec's O&M manual includes a section which presents the primary maintenance items and the procedures to be followed. Those items that required maintenance during the 30 day ETV test period have been evaluated.

3.1.2 Equipment Characteristics

3.1.2.1 Qualitative Factors

The following factors were defined by those personnel actually operating and monitoring the equipment:

- Susceptibility to changes in environmental conditions. The equipment was monitored to determine what conditions most affected ClorTec's performance claims. The nature and frequency of the changes required to maintain the operating conditions were used in the qualitative evaluation of the equipment.
- Operational reliability. Frequent equipment adjustments, particularly those that are significant, would have indicated relatively lower reliability and higher susceptibility to environmental conditions. Frequent adjustments would also indicate the degree of operator experience that may be required. The affect of operator experience with the ClorTec Model MC 100 system was also evaluated.
- Equipment installation. The degree of difficulty for equipment installation was evaluated through discussions with the United Water Pennsylvania personnel who performed the installation. As stated previously, the equipment used for the ETV test is a permanent installation, and was installed approximately two months prior to the initiation of testing. Equipment installation can add significantly to overall project cost and impact the overall effectiveness of operations.
- Raw materials. The "raw materials" used in the process of generating sodium hypochlorite were evaluated based on a review of "raw material" and equipment specifications.
- Byproducts. The byproduct(s) of the on-site SHG process were identified and evaluated in terms of handling and disposal of those byproduct(s), and levels of specific byproduct(s) through reactions of the generated sodium hypochlorite with the treated water.
- Equipment Safety. A review of the equipment O&M manual during the ETV testing period included identification of specific interlocked safety features and precautions. Some of these safety components were evaluated during the testing.

3.1.2.2 Quantitative Factors

The following factors of normal ClorTec Model MC 100 system equipment operations were quantified by various means in this Verification Testing Program:

- Power consumption. The amperage and voltage readings from the rectifier gauges and PLC display were recorded daily.
- Salt consumption. Daily salt consumption was measured indirectly by daily recording of softened water flow rate, the specific gravity of the diluted brine, and the daily recording of the accumulative hours of sodium hypochlorite generation.
- Softened dilution water consumption. The dilution water flow rate, and hours of generator operation provided a record of softened water consumption.
- Duration and frequency of sodium hypochlorite generation. The hours of generator operation and sodium hypochlorite storage tank levels were recorded daily.
- Frequency of softener regeneration. The softener regenerations were noted and recorded when they occurred.
- Estimated labor time for operation and maintenance. The time of operator attention was recorded daily.

3.1.3 Operating Parameters

In addition to the daily water quality analyses, measurement of the ClorTec Model MC 100 equipment's physical parameters were also recorded on a daily basis. This includes monitoring brine and sodium hypochlorite storage tank levels, dilution water flow rate, brine specific gravity, dilution water and brine temperatures, and rectifier amperage and voltage readings.

Table 3-1 presents all of the ClorTec Model MC 100 system operating parameters that were monitored and recorded during the ETV.

Table 3-1. Operational Parameter Monitoring and Data Collection Schedule

Parameter	Monitoring Frequency	Monitoring Method
Feed water flow rate	Once per day	Sum of individual WTP filter flow meters
Brine dilution water flow	Twice per day (adjust when 10% above or below target)	SHG rotameter and PLC/OIT display of converted signal transmitted from the SHG flow indicator
Total chlorine concentration in generator product	Twice per day	SM 4500-Cl B SM 4500-Cl F
Rate of feed stock consumption	Once per day	Record softened dilution water flow, the specific gravity of the diluted brine and daily hours of generator operation.

Table 3-1. Operational Parameter Monitoring and Data Collection Schedule (cont'd)

Parameter	Monitoring Frequency	Monitoring Method
Amperage & voltage	Once per day	Gauge readings
Diluted brine specific gravity	Once per day	Hydrometer and one liter graduated cylinder
Brine remaining in day tank	Once per day	Liquid level and gallon graduations on side of tank
Hypochlorite remaining in storage tanks	Once per day	Liquid level and 10 gallon graduations on side of tank
Softener waste stream composition	Once during softener regeneration	Grab samples for lab analysis
Softener waste stream flow rate	Twice during test period	Volumetric measurement ("Bucket and stopwatch")
Treated water flow rate	Twice per day	WTP finished water flow meter

3.2 Health and Safety Measures

3.2.1 Hydrogen Off-Gas

The only byproduct formed during the generation of sodium hypochlorite with the ClorTec system is hydrogen. The hydrogen gas is contained and vented outside the WTP building via piping and leak-proof connections from both the generator and sodium hypochlorite storage tanks. This eliminates the build-up of hydrogen gas in a confined space, which otherwise could potentially lead to an explosion.

3.2.2 Electrode Cleaners

Cleaning of the generator electrode plates requires a relatively mild acid solution. Protective clothing and eye protection are recommended when handling even mild acids. Specific protective equipment recommendations and handling procedures provided in the O&M were reviewed during the ETV testing period and appear to be adequate.

3.3 Communications, Logistics and Data Handling Protocol

It was essential that Gannett Fleming, as the FTO, coordinate lines of communication due to the number of participants involved in the test program. Documentation of study events was facilitated through the use of a logbook, photographs, data spreadsheets, and laboratory chain-of-custody forms. Data handling is a critical component of any equipment evaluation or testing. Care in handling data assures that the results are accurate and verifiable. Accurate sample analysis is meaningless without verifying that the numbers being entered into spreadsheets and reports are accurate, and that the results are statistically valid.

3.3.1 Introduction

The data management system used in the verification testing program involved the use of both custom computer spreadsheet software and manual recording methods for daily logging of operational parameters. United Water Pennsylvania staff manually recorded daily operating parameters in the field data logbook. On a weekly basis, designated United Water Pennsylvania staff entered this data into custom prepared computer spreadsheets. Electronic copies of these spreadsheets and paper copies of the logsheets were collected by Gannett Fleming personnel on a weekly basis. Gannett Fleming personnel printed "hard copies" of the spreadsheets and compared the data entries to the copied logsheet data. Laboratory water quality reports were submitted to Gannett Fleming by Microbac Laboratories approximately every two weeks. The laboratory results from these reports were checked, entered into computer spreadsheets and then rechecked.

3.3.2 Objectives

There were two primary objectives related to data handling. The first objective was to establish a viable structure for the recording and transmission of field testing data so that Gannett Fleming would generate sufficient and reliable analytical data for verification purposes. The second objective was to develop a statistical analysis of the data, as described in the EPA/NSF ETV *Protocol for Equipment Verification Testing for Inactivation of Microbiological Contaminants*, August 1999.

3.3.3 Procedures

Specific established data handling procedures were used for handling all aspects of the verification data, photographs taken during the study for documentation, the use of chain-of-custody forms, the gathering of on-line instrument measurements, entry of data into customized computer spreadsheets, and methods of performing statistical analyses.

These procedures are presented in Section 3.8.3.

3.4 Recording Statistical Uncertainty

For the analytical data obtained during verification testing, 95 percent confidence intervals were calculated by Gannett Fleming for selected water quality parameters. Water quality parameters included chlorine residual (both free and total), pH, alkalinity, turbidity, UV_{254} and HPC.

The consistency and precision of water quality data can be evaluated with the use of the confidence interval. A confidence interval describes a population range in which any individual population measurement may exist with a specified percent confidence. The following formula was employed for confidence interval calculation:

$$\text{confidence interval} = \overline{X} \pm t_{n-1,1-\frac{\alpha}{2}} (S / \sqrt{n})$$

where: $\overline{X}$ is the sample mean;

S is the sample standard deviation;
n is the number independent measures included in the data set;
t is the Student's t distribution value with n-1 degrees of freedom; and
$\propto$ is the significance level, defined for 95% confidence as: 1 - 0.95 = 0.05.

According to the 95% confidence interval approach, the $\propto$ term is defined to have the value of 0.05, thus simplifying the equation for the 95% confidence interval in the following manner:

$$95\% \text{ confidence interval} = \overline{X} \pm t_{n-1,0.975}(S/\sqrt{n})$$

Results of these calculations are expressed as the sample mean plus or minus the width of the 95% confidence interval.

3.5 Verification Testing Schedule

Verification testing activities included equipment verification operations, sampling and analysis. The test schedule was developed to encompass all of these activities.

The 30 day test was initiated on March 8, 2000, following the receipt of an operating permit by United Water Pennsylvania for the ClorTec Model MC 100 system from the PADEP, and completed April 6, 2000.

3.6 Verification Task Procedures

3.6.1 Task 1: Equipment Operation and Disinfectant Production Capabilities

During Task 1, Gannett Fleming evaluated equipment operations and determined the rates of feed water flow and sodium hypochlorite production concentration for which the SHG system was designed.

The following are the objectives of this task:

- Establish SHG equipment generation range.
- Define chlorine concentration range and species.
- Document feed water quality.
- Determine power and raw material consumption.

The protocol for start-up presented in Section 5 of *ClorTec MC Series Operator Interface Manual* was used and evaluated for initial startup of the ClorTec Model MC 100 system.

3.6.2 Task 2: Treated Water Quality

Water quality data was collected during the equipment operation test run of Task 1.

The objective of this task was to assess the impact on treated water quality of feeding sodium hypochlorite generated on-site.

The following sources were characterized for water quality: Feed Water (WTP combined filter effluent), Concentrated Sodium Hypochlorite Stream, (ClorTec Model MC 100 generated sodium hypochlorite), Treated Water (WTP finished water) and Softener Regenerant Wastewater. The feed water, concentrated sodium hypochlorite stream and treated water quality were characterized by measurement of the parameters listed in Table 3-2. The characteristics of the feed water are explicitly stated in reporting data from Task 1.

Samples were analyzed on-site, or off-site by Microbac Laboratories, Inc. EPA method numbers and *Standard Methods* reference numbers are indicated on Table 3-2 for both the field and laboratory analytical procedures. All laboratory samples were collected in appropriate containers, with preservatives, as applicable, prepared by Microbac Laboratories. Chain-of-custody forms accompanied all samples submitted to Microbac Laboratories.

The ClorTec Model MC 100 system at the Hummelstown WTP is used for both primary and residual (distribution system) disinfection. Organic and inorganic disinfection byproduct (DBP) analyses were conducted on an instantaneous basis for both primary and residual disinfection samples. Samples collected for DBP analyses were collected at the same time as samples for pH, alkalinity, UV_{254}, turbidity, ammonia, true color, iron and manganese. This places other water quality results in the context of the water quality parameters that may have an affect on DBP concentrations.

SDS testing was performed once during steady-state operation of the ClorTec Model MC 100 system. SDS was used to estimate DBP formation in the distribution system including total trihalomethanes (TTHM), haloacetic acids (HAA5), chlorite and chlorate. Since additional dosing of the sodium hypochlorite is used for residual disinfection subsequent to primary disinfection, the SDS method as specified in the EPA ICR Manual was performed by collecting a sample of the sodium hypochlorite treated water, spiking it with an additional dose of sodium hypochlorite disinfectant to achieve the Uniform Formation Conditions (UFC), chlorine residual, and incubating the sample in the dark under UFC.

The following UFC was used for the SDS testing:

- Incubation period of 24 " 1 hour
- Incubation temperature of 20 " 1.0EC
- Buffered pH of 8.0 " 0.2
- 24-hour chlorine residual of 1.0 " 0.4 mg/l

No comparison of DBP formation between alternate disinfectants was performed.

Table 3-2. Water Quality Sampling Schedule

Parameter	Frequency	Source	Method
On-Site Analyses			
pH	Daily	Feed, Treated, Wastewater[1]	SM 4500 H+
Temperature	Daily	Feed, Treated, Wastewater[1]	SM 2550 B
Turbidity	Daily	Feed, Treated	SM 2130 B
Chlorine Disinfectant Residual	Twice/Day	Concentrated Sodium Hypochlorite Stream, Feed, Treated, Wastewater[1]	4500 Cl B 4500Cl F 4500 Cl G
Hydrogen Sulfide	Once/Day	Feed	Hach Field Test Kit Model HS-C (Color chart/ Effervescence of H_2S)
Laboratory Analyses			
Alkalinity	Weekly	Feed, Treated, Wastewater[1]	SM 2320 B
TDS	1/Test Period	Feed, Treated, Wastewater[1]	SM 2540 C
Ammonia Nitrogen	Weekly	Feed, Treated	SM 4500 NH D
UVA	Weekly	Feed, Treated	SM 5910
True Color	Weekly	Feed, Treated	SM 2120 B
Iron	1/Test Period	Feed, Treated	EPA 200.7
Manganese	1/Test Period	Feed, Treated	EPA 200.7
Chloride	1/Test Period	Feed, Treated	SM 4500 C
Bromide	1/Test Period	Feed, Treated	EPA 300.0
Sodium	1/Test Period	Feed, Treated	EPA 200.7
Total Coliform Bacteria	5/Week	Feed, Treated	SM 9223
HPC	5/Week	Feed, Treated	EPA 600878017
TTHM	1/Test Period	Feed, Treated	EPA 524.2
HAA5	1/Test Period	Feed, Treated	SM 6251B
Chlorite	1/Test Period	Feed, Treated	EPA 300.0
Chlorate	1/Test Period	Feed, Treated	EPA 300.0
DBP Formation Testing[2]			
TTHM	1/Test Period	Treated	EPA 524.2
HAA5	1/Test Period	Treated	SM 6251 B
Chlorite	1/Test Period	Treated	EPA 300.0
Chlorate	1/Test Period	Treated	EPA 300.0

(1)Softener regenerate wastewater
(2)Conditions for DBP Formation Testing preparation follow the UFC proposed in the Information Collection Rule.

3.6.3 Task 3: Data Management

The data management system used in the Verification Testing involved the use of custom computer spreadsheets and a field data logbook.

The following were the objectives of this task:

- Establish a viable structure for the recording and transmission of field testing data by Gannett Fleming such that sufficient and reliable data are generated for verification purposes.

- Develop a statistical analysis of the data as described in the EPA/NSF ETV *Protocol For Equipment Verification Testing of Microbiological Contaminant Inactivation*, August 1999.

The field testing operators recorded all operating data and on-site water quality analyses by hand on a daily daily basis in a field data logbook. The logbook is permanently bound with consecutively numbered pages. The pages indicate the starting and ending dates that apply to entries in the logbook. Each page of the logbook has an appropriate heading to avoid entry omissions. All logbook entries were made in black ink, although permanent ink was not used due to its tendency to "bleed through" the logbook pages. Corrections in the logbook were made by placing one line through the erroneous information and initialing by the line. A comments section was provided in the logbook for each test day to record any testing problems, issues, etc. The original logbook was stored on site, and was photocopied once per week to provide a backup record and for transfer of logbook data to Gannett Fleming. This data protocol not only eased referencing the original data, but offered protection of the original records.

The electronic database for the project was set up in the form of custom-designed spreadsheets. The spreadsheets are capable of storing and manipulating data for each monitored water quality and operational parameter from each task, each sampling location, and each sampling time. All data from the field data logbook was entered into the appropriate spreadsheets. Data entries for all on-site operating data were conducted by the designated field testing operator. Following data entry, each spreadsheet was printed out and the print-out was checked against the handwritten data. Any corrections were noted on the hard copies and corrected on the screen, and then a corrected version of the spreadsheet was printed out. Each step of the verification process was initialed by the field testing operator performing the entry or verification step. Following transmission of spreadsheets and copies of logbook sheets to Gannett Fleming, data entries were rechecked by the Gannett Fleming project engineer.

Samples for off-site water quality analyses were collected and sent to Microbac Laboratories. The data were tracked by use of the following abbreviations for the sample locations: feed water-FW, treated water-TW, softener wastewater-SW. Data from Microbac Laboratories were received and reviewed by Gannett Fleming. These data were entered into the appropriate lab spreadsheets, corrected, and verified in the same manner as the field data.

Water quality data from grab sample analyses, collected according to the Water Quality Sampling Schedule (Table 3-2) in Task 2, were evaluated for statistical uncertainty. For example, Gannett Fleming calculated the mean values, standard deviations, and 95 percent confidence intervals for grab sample data obtained during the Verification Testing as described in the *Protocol for Equipment Verification Testing of Microbiological Contaminant Inactivation*, August 1999. Statistical analysis can be carried out for water quality data obtained under a large variety of testing conditions. The statistics developed will be helpful in demonstrating the degree of reliability with which the sodium hypochlorite generation system can attain quality goals.

3.6.4 Task 4: Quality Assurance/Quality Control (QA/QC)

The objective of this task was to maintain strict QA/QC methods and procedures during the ClorTec Model MC 100 system Verification Testing program. Maintenance of strict QA/QC procedures was important in that if a question arises when analyzing or interpreting data, it will be possible to verify exact conditions at the time of testing.

Equipment flow rates and associated signals were verified and verification recorded on a daily basis. A twice-daily walk-through during testing was conducted to verify that each piece of equipment or instrumentation was operating properly. On-line monitoring equipment, such as flow meters, were checked to verify that the read-out matched with the actual measurement and the signal being recorded was correct. The QA/QC items listed below were conducted in addition to any specified QA/QC procedures required with the analytical methods listed on Table 3-2.

3.6.4.1 Turbidity

- The four on-line filter effluent turbidimeters (feed water turbidity) and the treated water turbidimeter were calibrated one time at the beginning of the test with formazin solution (primary standard).
- The bench turbidimeter was calibrated one time at the beginning of test with formazin solution at the following standards: 0.1 NTU, 0.5 NTU and 5.0 NTU.
- The bench turbidimeter was checked daily with secondary standards.
- The on-line turbidimeter readings were compared with the bench turbidimeter readings for both feed water and treated water.
- The treated water on-line turbidimeter sample flow rate was checked daily; feed water on-line turbidimeter sample flow rates were checked one time only, at the beginning of the test, due to equipment accessibility problems.

3.6.4.2 pH

- The bench pH meter was calibrated daily with certified 7.0 and 10.0 buffer solutions. The pH probe was stored in the appropriate solution, as defined in the instrumentation manual.
- The on-line treated water pH meter was calibrated at the beginning of test; the on-line pH probe was replaced on 3/13/00 and recalibrated; the on-line pH meter was recalibrated again on 3/15/00.
- The on-line treated water pH readings were compared with bench pH analyses of treated water.

3.6.4.3 Chlorine Residual

- The total chlorine analyses of the hypochlorite generator stream were conducted twice daily with two different method analyses, SM 4500-Cl B and SM 4500-Cl F.
- The twice daily on-line free chlorine readings of treated water were compared with treated water grab samples analyzed for free chlorine.

- The twice daily on-line free chlorine readings of feed water were compared with treated water grab samples analyzed for free chlorine.

3.6.4.4 Temperature

- The on-line temperature readings of the treated water were compared with treated water grab samples checked for temperature, using a NIST-traceable thermometer.
- The on-line temperature readings of the heated dilution water were compared with the temperature of heated dilution water grab samples using a NIST-traceable thermometer.

3.6.4.5 Brine Dilution Water Flow

- The dilution water flow rate was measured continuously with two different instruments mounted on the generator cabinet: 1) a rotometer reading in units of gpm, and 2) a sight flow instrument that transmitted rpm to the PLC which converted this signal to milliliters per minute. The flow rates from these instruments were recorded by hand at the same time on a daily basis. (calibration with “bucket and stopwatch” was not done for either instrument due to the difficulty involved in disconnecting plumbing).
- The treated water flow meter was calibrated once at the beginning of the test as indicated in Appendix G.

3.6.4.6 Power

- The amp and volt readings were recorded from the PLC display daily, and compared to local readings on gauges mounted on the rectifier.

3.6.4.7 Softener Regeneration Wastewater Flow Rate

- The softener wastewater flow rate was calculated based on the time of regeneration and the collection of the wastewater in a polyethylene drum with gallon graduations.

3.6.4.8 Diluted Brine Concentration

- The brine solution diluted in the ratio of 1:10 with softened water was checked daily for specific gravity and temperature using a hydrometer and NIST-traceable thermometer. This information together with the chart in Appendix A was used to determine actual diluted brine concentrations.

3.6.4.9 Equipment Tubing and Connections

- All tubing and connections were checked daily for leaks.

3.6.4.10 Sodium Hypochlorite Metering Pumps

- Prechlorine and post chlorine metering pumps were checked once daily for calibration using “stopwatch and calibration tube”.

When results of the twice-daily, daily, bi-weekly and one time equipment monitoring indicated possible questionable data results, the data was rejected and resampling occurred.

3.6.4.11 Chemical and Biological Samples Shipped Off-Site for Analyses

Microbac Laboratories was used for the analysis of off-site chemical and biological parameters. As a Pennsylvania-certified laboratory for drinking water, it follows all preservation, delivery, hold time and analytical procedures contained in either *Standard Methods for the Examination of Water and Waste Water*, 18th or 19th Edition (1992, 1995) or *Methods for Chemical Analysis of Water and Wastes* (1979). Sample collection was performed by either United Water Pennsylvania operations staff or the Gannett Fleming engineer providing ETV supervision.

3.6.4.11.1 Organic Parameters. Organic parameters analyzed during the verification testing were true color, UVA_{254}, TTHM and HAA5. (Sample bottles left on-site for laboratory TOC analysis were used by United Water Pennsylvania staff for non-ETV sampling and, inadvertently, were not replaced; TOC samples were never collected). Samples for analysis of true color and UVA_{254} were collected in glass bottles supplied by Microbac Laboratories and hand-carried to the Laboratory by Gannett Fleming personnel immediately after collection. True color and UVA_{254} samples were collected, preserved, held and analyzed in accordance with *Standard Methods* 2120B and 5910, respectively. Storage time before analysis was minimized in accordance with *Standard Methods*.

Samples for analysis of TTHM and HAA5 were collected in glass vials with teflon caps supplied by Microbac Laboratories and hand-carried to the laboratory by Gannett Fleming after completion of SDS testing. TTHM and HAA5 samples were collected, preserved and held in accordance with EPA method 524.2 and *Standard Method* 6251B, respectively.

3.6.4.11.2 Microbiological Parameters. Microbiological parameters analyzed during the verification testing were Total Coliform and HPC. HPC and Total Coliform samples were collected, held and analyzed according to procedures outlined in EPA Method 6008780017 and *Standard Method* 9223, and hand-carried to the laboratory by a Microbac Laboratories representative.

3.6.4.11.3 Inorganic Parameters. True color and UVA_{254} samples were collected, preserved, held and analyzed in accordance with *Standard Methods* 2120B and 5910, respectively.

Inorganic chemical samples alkalinity, ammonia nitrogen, chloride and TDS were collected, preserved and held in accordance with *Standard Methods* 2320B, 4500 NHD, 4500 C and 2540 C, respectively.

Inorganic chemical samples bromide, chlorate and chlorite were collected, preserved and held in accordance with EPA Method 300.0.

Inorganic chemical samples iron, manganese and sodium were collected, preserved and held in accordance with EPA Method 200.7.

Chapter 4
Results and Discussions

4.1 Introduction

The ETV testing for the ClorTec MC 100 system was initiated on March 8, 2000 and concluded on April 6, 2000.

The verification testing site was United Water Pennsylvania's Hummelstown WTP, located in the Borough of Hummelstown, Pennsylvania. The equipment was located in the chemical room of the WTP.

This section of the verification report presents the results of the testing and offers discussion of the results. Results and discussions encompassed the concentration of sodium hypochlorite generated, feed and treated water quality, and equipment characteristics. QA/QC procedures are also presented in this section of the report.

4.2 Verification Task Results

4.2.1 Task 1: Equipment Operation and Disinfectant Production Capability

The SHG system operated in auto batch mode. Daily operations consisted of monitoring the SHG system, conducting on-site water quality analyses, and recording equipment operating data.

Daily operating data recorded for the entire 30-day verification test are presented in Appendix C.

4.2.1.1 Range of Treated Water Flow Rates

The treated water flow varied between 1075 gpm and 1893 gpm over the 30-day test period, with a mean of 1419 gpm. Treated water flow rates recorded twice daily are presented on Figure 4-1.

4.2.1.2 Range of Chlorine Concentrations in Generator Stream

The total chlorine concentration in the sodium hypochlorite generator stream was analyzed using two different methods of chlorine analysis, *Standard Methods* (SM) 4500-Cl B and SM4500-Cl F. The generator stream average total chlorine concentration using either chlorine method was essentially the same, 0.90% for SM4500-Cl B and 0.91% for SM4500-Cl F. *Standard Method* 4500-Cl F, which is the EPA-approved method required for this testing, had a slightly greater total chlorine variability then occurred with SM4500-Cl B. A comparison of the daily results from the two methods is presented on Figures 4-2 and 4-3. Table 4-1 presents a summary of the results.

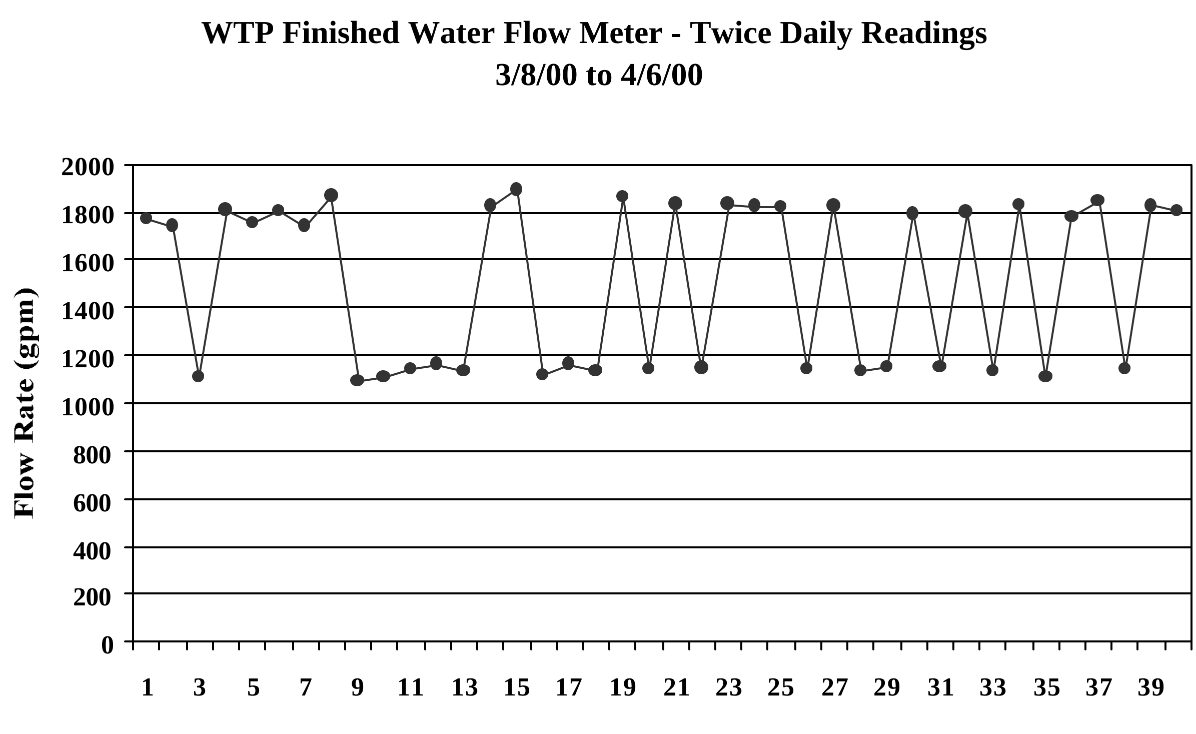


Figure 4-1. ETV Treated Water Flow Rate

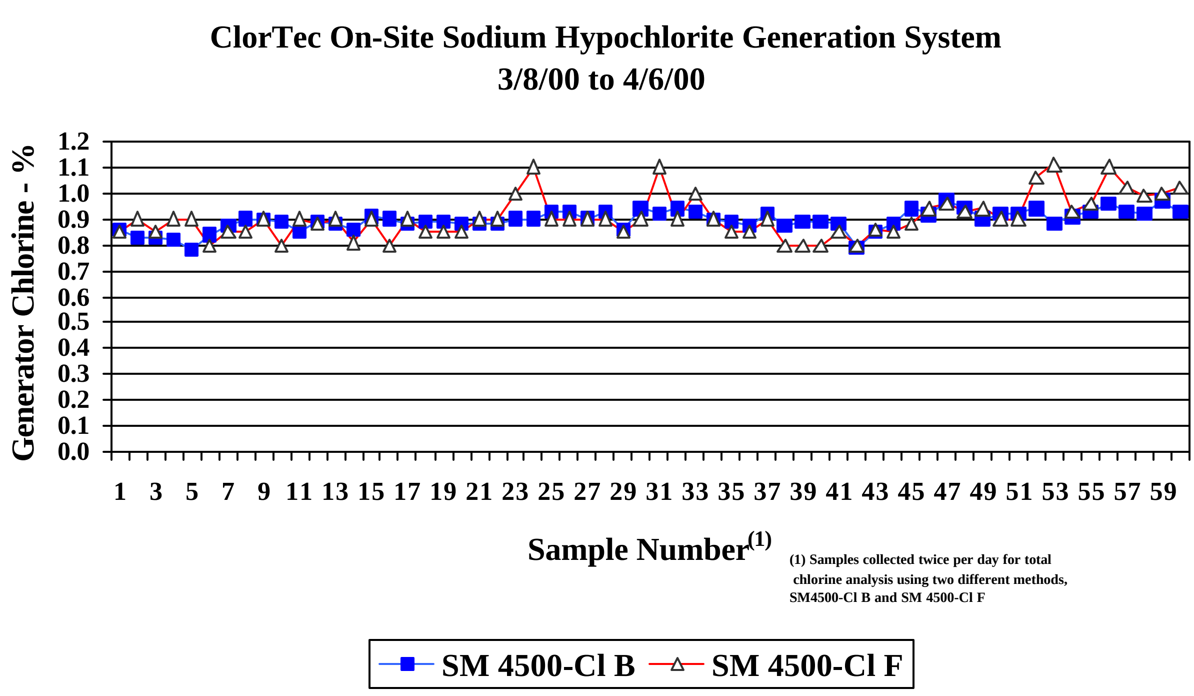


Figure 4-2. Hypochlorite Generator Chlorine Concentration

The greater variability in results for SM4500-Cl F is probably due to the significant potential for error in sample dilutions that are required as part of this procedure (see "Testing Procedures for High Chlorine Concentrations" in Appendix B).

Table 4-1. On-Site Chlorine and Brine Analyses

	Treated Water			Hypochlorite Generator		Brine		
	FAC FAS[1] (mg/l)	FAC On-Line (mg/l)	TAC FAS[1] (mg/l)	TAC FAS[1] (%)	TAC Iodo[2] (%)	NaCl (%)	Sp. Gr.	Temp. (°C)
Mean	1.33	1.23	1.46	0.91	0.90	3.53	1.024	24
Minimum	1.05	1.00	1.00	0.80	0.78	3.04	1.020	18
Maximum	1.80	1.69	2.00	1.11	0.97	3.90	1.026	27
Standard Deviation	0.17	0.16	0.22	0.08	0.04	0.23	0.002	1.9
95% Confidence Interval	1.33 ± 0.04	1.23 ± 0.04	1.46 ± 0.05	0.91 ± 0.02	0.90 ± 0.01	3.53± 0.08	1.024± 0.001	24 ± 0.68

(1) FAS = Ferrous Ammonium Sulfate Titration (*Standard Method* 4500-Cl F)
(2) Iodo = Iodometric Titration (*Standard Method* 4500-Cl B)
FAC=Free Available Chlorine
TAC=Total Available Chlorine

The results of the total chlorine analyses of the hypochlorite generator stream using the two chlorine analysis methods are compared to the diluted sodium chloride (NaCl) concentration in percent on Figure 4-3. There appears to be a rough correlation between the sodium chloride concentration and the chlorine concentration.

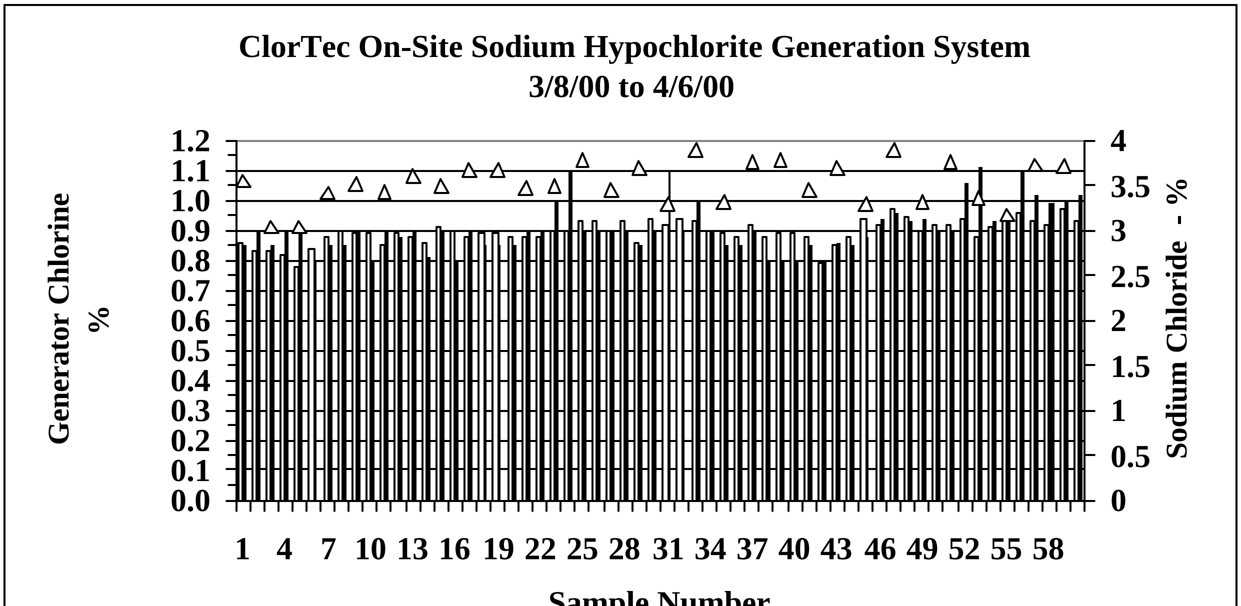


Figure 4-3. Hypochlorite Generator Chlorine and Sodium Chloride Concentrations

The percent sodium chloride concentration was determined by first collecting a sample of brine in a one liter graduated cylinder just before it entered the generator. A hydrometer was used to measure the specific gravity of the brine. The average specific gravity of 1.024 was within the target range stated in the *ClorTec MC Operator Interface PLC Manual* of approximately 1.023 to 1.025. A NIST-traceable thermometer was used to measure the temperature of the brine. The average brine temperature of 24°C (76°F) was in the acceptable range of greater than 50°F and less than 80°F. These measurements were used with the chart in Appendix A to determine the percent sodium chloride.

Figure 4-3 presents a trend of erratic but generally increasing sodium chloride concentrations; the total chlorine levels in the concentrate stream generally correlated with this trend. If the average generator chlorine concentration of 0.91% is adjusted by the target sodium chloride concentration of 3.00% divided by the actual average sodium chloride concentration of 3.53%, the average adjusted total chlorine concentration is 0.77%, which is within ClorTec's performance claim. This assumes a linear relationship between sodium chloride concentration and generator hypochlorite concentration, which cannot be determined from the data presented on Figure 4-3. Since the dilution water flow of 1.0 gpm was generally confirmed with two different flow meters, the bellows pump was probably delivering brine at a rate higher than the 0.1 gpm specified, producing sodium chloride and chlorine concentrations above the targeted levels.

The percent sodium chloride concentration is compared to the dilution water flow rate on Figure 4-4.

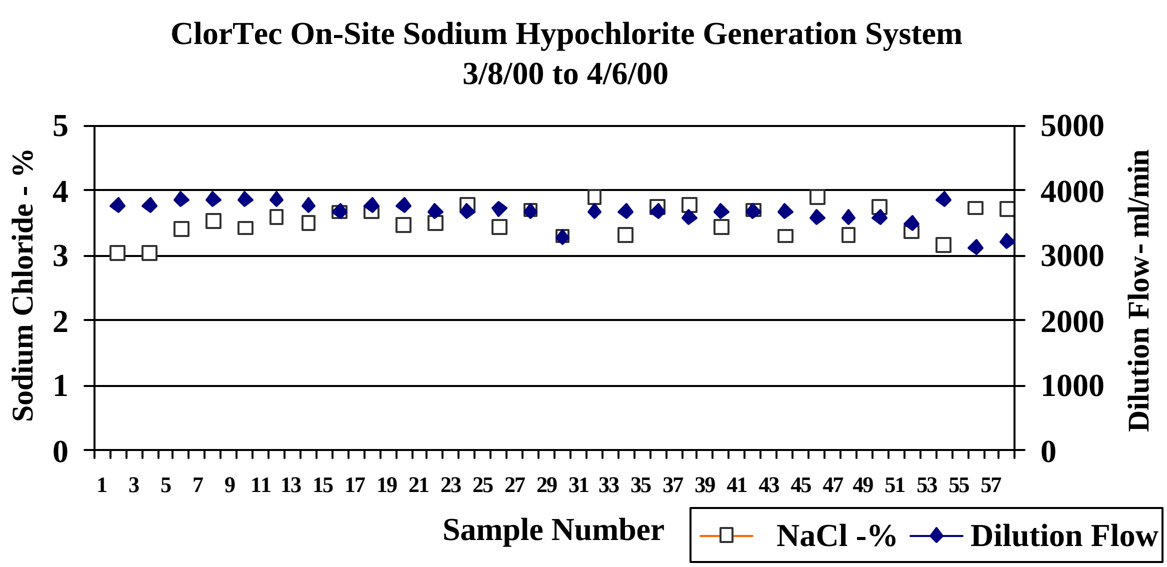


Figure 4-4. Sodium Chloride Concentration and Dilution Water Flow

There appears to be somewhat of a correlation between dilution water flow and sodium chloride concentration; generally the higher the dilution flow, the lower the sodium chloride concentration.

4.2.1.3 Range of Treated Water Chlorine Residuals

The mean values for free and total chlorine residual in the treated water using SM 4500-Cl F were 1.32 mg/l and 1.46 mg/l, as presented on Table 4-1. Free chlorine was greater than 90% of total chlorine due to the majority of the chlorine demand having been removed and/or satisfied with prechlorination, coagulation, clarification and filtration.

In addition to the bench analyses, treated water free chlorine was also monitored with an on-line chlorine residual analyzer. Data from this instrument were recorded at the same time that grab samples were collected for chlorine residual analysis. The average of recorded on-line analyses was around 10% less than the grab sample analyses.

The WTP post sodium hypochlorite metering pump was manually adjusted to account for changes in WTP flow and feed water quality in order to maintain a treated water free chlorine residual between 1.0 mg/l and 2.0 mg/l.

The minimum and maximum daily feed rates of post sodium hypochlorite during the test period, presented on Table 4-2, were approximately 14 lbs/day and 39 lbs/day, respectively. Since the SHG system supplies both the pre and post chlorine feed requirements, the system appears to be adequately sized at 100 lbs/day, with 100% redundancy in the event that one of the two 50 lb/day electrolytic cells should fail.

Table 4-2. Total Chlorine Analyses and Sodium Hypochlorite Feed Rates

	Feed Water TAC FAS(1)	Treated Water TAC FAS(1)	Treated Water Flow	Sodium Hypochlorite Generator TAC FAS(1)		WTP Post Sodium Hypochlorite Metering Pump Feed Rate
	(mg/l)	(mg/l)	(gpm)	(%)	(mg/l)	(ml/min)
Mean	0.51	1.46	1419	0.91	9,160	781
Minimum	0.08	1.14	1075	0.80	8,000	500
Maximum	1.58	2.00	1893	1.11	11,100	1210
Standard Deviation	0.29	0.22	346	0.08	748	189
95% Confidence Interval	0.51± 0.07	1.46± 0.05	1419± 124	0.91± .02	9160± 265	781±68

TAC=Total Available Chlorine
(1) FAS=Ferrous Ammonium Sulfate Titration (SM4500-ClF)
N/A=Not Applicable because standard deviation=zero

4.2.1.4 Softener Wastewater Characterization

An ion exchange softener was used to treat dilution water for the brine saturator tank and water used for dilution of the 30 percent brine solution. The softener required regeneration, and was based on the volume of water softened. Regeneration was completely automated.

The frequency of softener regeneration and the consequent discharge of regenerant wastewater was dependent on the daily operating time for the SHG system. If WTP production rate was at the higher end of the range that occurred during the test period, daily softener regeneration was required. Otherwise, softener regeneration occurred every two to three days. The water quality of regenerant wastewater, presented on Table 4-3, was characterized as being of relatively low pH, averaging less than 6.5, and low alkalinity, approximately 24 mg/l. This compares with the unsoftened feed water pH of 7.0 and alkalinity of 30 mg/l. The result of the only analysis for

TDS of the regenerant wastewater was 7,785 mg/l, an indication of very high dissolved mineral concentration, in comparison with one unsoftened feed water sample TDS analysis of 139 mg/l.

Table 4-3. Softener Regenerant Wastewater Quality

	Alkalinity (mg/l CaCO3)	TDS (mg/l)	Bromide (mg/l)	pH	Temp. (ºC)	FAC FAS(2) (mg/l)	TAC FAS(2) (mg/l)
Mean	24	7,785	NA(1)	6.5	12.4	1.71	2.07
Minimum	17	7,785	NA	5.8	9.2	0.25	0.50
Maximum	31	7,785	NA	7.4	17.3	9.00	9.30
Standard Deviation	7.0	0	NA	0.41	2.16	2.05	2.39
95% Confidence Interval	24 ± 8	N/A	NA	6.5 ± 0.2	12.4 ±1.03	1.71 ±0.95	2.07±1.10

(1)Bromide could not be analyzed due to masking by high chloride concentration.
(2)FAS=Ferrous Ammonium Sulfate Titration (*Standard Method* 4500-Cl F).
NA=Not Analyzed
N/A=Not Applicable because standard deviation=0

The softener regenerated at a flow rate of 2.85 gpm for approximately ten minutes to produce a total regenerate wastewater volume of around 30 gallons per regeneration. Although the concentration of TDS is very high, the volume of wastewater is insignificant relative to the quantity of process wastewater in the WTP wastewater lagoons. Dilution in the lagoons should result in a negligible increase in TDS in the lagoon NPDES discharge. Therefore, no special handling of this regenerant wastewater is anticipated.

4.2.1.5 Feed Stock Consumption

Feed stock consisted of a solar grade salt and softened water used to dilute the salt into a brine solution. An analysis of the salt used in the ETV test indicated it was 99.0% pure sodium chloride; the calcium concentration was less than 0.23% (see Appendix H). The calcium concentration is important due to the scaling effect it can have on the generator electrode plates. Despite the low to moderate level of hardness in the feed water, the WTP treated water used for brine dilution must be softened to minimize the calcium concentration. Table 4-4 presents a summary of daily consumption of salt and softened water for the 30 day test period.

Table 4-4. Daily Feed Stock Consumption

	Generator Operating Time (min)	Total Softened Water (gpd)	Salt (lbs)
Mean	790	842	247
Minimum	180	189	59
Maximum	1500	1681	481
Standard Deviation	280	299	91
95% Confidence Interval	790±119.6	842±131.7	247±37.9

4.2.1.6 Power Consumption

Power consumption was recorded daily for voltage and amperage, which was displayed locally on the power supply/rectifier, and remotely on the PLC cabinet LCD screen. Summary data for these recordings are presented on Table 4-5.

Table 4-5. Daily Power Consumption	Amperage		Voltage	
	Rectifier (amps-DC)	PLC (amps-DC)	Rectifier (volts)	PLC (volts)
Mean	183	184	46	46
Minimum	170	183	45	45
Maximum	185	185	48	48
Standard Deviation	4.6	0.5	0.8	0.8
95% Confidence Interval	183±1.6	184±0.2	46±0.3	46±0.3

The *ClorTec MC Operator Interface Manual* states that for Model MC 100 the voltage and amperage should be approximately 48 volts and 185 amps. The average voltage and amperage results during the ETV are within 4% and 2%, respectively, of these levels.

4.2.2 Task 2: Water Quality

As stated previously, the feed water treated by the SHG system was surface water that had undergone prechlorination supplied by the same SHG system, followed by coagulation, clarification and dual media granular filtration. As a result, the feed water turbidity was low, averaging 0.06 NTU during the verification testing. A free chlorine residual was maintained in the feed water, averaging 0.36 mg/l during the test period. Due to the high quality filtered water and the chlorine demand having been satisfied with prechlorination, the addition of post sodium hypochlorite provided a free available chlorine residual for achieving compliance with CT requirements under the EPA Surface Water Treatment Rule (SWTR), and provide a residual disinfectant throughout the distribution system.

4.2.2.1 On-Site Analytical Results

Table 4-6 summarizes the results of on-site analytical testing for the 30 day verification test. The only change in water quality of any significance between the feed water and treated water was the concentration of chlorine. The addition of post sodium hypochlorite resulted in an average total chlorine concentration of 1.46 mg/l, an increase of 0.95 mg/l over feed water total chlorine level. As stated previously, the treatment prior to post sodium hypochlorite either removed or satisfied almost all of the chlorine demand, resulting in post chlorine being available largely as free chlorine.

Sodium hypochlorite had no impact on the pH of the treated water due to the insignificant quantity fed relative to the treated water flow.

Sodium hypochlorite had no effect on the turbidity level in the treated water. Turbidity averaged 0.06 NTU in both the feed and treated water.

Hydrogen sulfide was not detected in the feed water. The minimum method detection level was 0.1 mg/l.

Table 4-6. On-Site Water Quality Analyses

	Feed Water (Filter Room Pumped Sample)							Treated Water (Finished Water - Lab Sink)								Hypochlorite Generator	
			Turbidity								Turbidity		FAC		TAC	TAC	
	Bench pH	Bench Temp. (°C)	Bench (NTU)	On-line (NTU)	Bench H_2S (mg/l)	On-line FAC (mg/l)	TAC FAS(1) (mg/l)	On-line pH	Bench pH	Bench Temp. (°C)	Bench (NTU)	On-line (NTU)	FAS(1) (mg/l)	On-line (mg/l)	FAS(1) (mg/l)	FAS(1) (%)	Iodo(2) (%)
Mean	7.0	11.4	0.067	0.060	0	0.36	0.51	7.07	7.0	11.6	0.063	0.059	1.32	1.23	1.46	0.90	0.89
Minimum	6.2	7.5	0.040	0.040	0	0.01	0.08	6.80	6.5	7.9	0.046	0.040	1.05	1.00	1.00	0.80	0.78
Maximum	7.6	15.1	0.100	0.094	0	1.38	1.58	7.53	7.4	15.5	0.100	0.098	1.80	1.69	2.00	1.11	0.97
Standard Deviation	0.32	1.9	0.017	0.014	0	0.24	0.29	0.16	0.2	1.9	0.013	0.014	0.16	0.16	0.22	0.08	0.04
95% Confidence Interval	7.0± 0.12	11.4± 0.66	0.067± 0.006	0.060± 0.005	N/A	0.36± 0.06	0.51 ± 0.08	7.07± 0.06	7.0± 0.08	11.6± 0.67	0.063± 0.005	0.059± 0.005	1.32± 0.04	1.23± 0.04	1.46± 0.05	0.90± 0.02	0.89± 0.01

(1) FAS=Ferrous Ammonium Sulfate Titration (Standard Method 4500-Cl F)
(2) Iodo=Iodometric Titration (Standard Method 4500-Cl B)
FAC=Free Available Chlorine
TAC=Total Available Chlorine
N/A=Not Applicable because standard deviation=0

4.2.2.2 Feed and Finished Water Testing Results

Six inorganic contaminants commonly found in water supplies, presented on Table 4-7, were analyzed in the feed water and treated water once during the test period. Iron, manganese and bromide were below detection limits in both the feed water and treated water. TDS, sodium and chloride were approximately 10 percent higher in the treated water relative to the feed water. This is likely due to the addition of sodium hypochlorite to the feed water process. The TDS of the softener wastewater was much higher than the feed water due to the removal and concentration of dissolved minerals in the softener treatment process.

Table 4-7. Feed, Treated, and Softener Water Quality - Laboratory Analyses

Parameter	Feed Water	Treated Water	Softener Wastewater
TDS (mg/l)	139	147	7,785
Iron (mg/l)	<0.03	<0.03	NA
Manganese (mg/l)	<0.01	<0.01	NA
Chloride (mg/l)	23.8	27	NA
Bromide (mg/l)	<0.02	<0.02	NA
Sodium (mg/l)	11.6	13.3	NA

NA=Not Analyzed

Tables 4-8 and 4-9 present the results of weekly feed water and treated water analyses for alkalinity, ammonia, UV_{254} and true color. The presence of ammonia can have a significant impact on disinfection due to the demand it places on chlorine. No ammonia was detected in either the feed water or treated water.

The impact of feeding sodium hypochlorite on the alkalinity level was negligible. Feed water and treated water alkalinity levels were essentially the same.

Table 4-8. Weekly Feed Water Quality - Laboratory Analyses	Alkalinity (mg/l $CaCO_3$)	Ammonia (mg NH_3-N/L)	UV_{254} (cm^{-1})	True Color (C.U.)
Mean	28	<0.10	0.021	5
Minimum	15	<0.10	0.017	5
Maximum	37	<0.10	0.023	5
Standard Deviation	11	0	0.003	0
95% Confidence Interval	28 ± 10.41	N/A	0.021 ± 0.003	N/A

N/A=Not Applicable because standard deviation=0

Table 4-9. Weekly Treated Water Quality - Laboratory Analyses	Alkalinity (mg/l$CaCO_3$)	Ammonia (mg NH_3-N/L)	UV_{254} (cm^{-1})	True Color (C.U.)
Mean	30	<0.10	0.020	5
Minimum	23	<0.10	0.016	5
Maximum	37	<0.10	0.023	5
Standard Deviation	7	0	0.003	0
95% Confidence Interval	30 ± 7.12	N/A	0.020 ± 0.003	N/A

N/A=Not Applicable because standard deviation=0

UV_{254} and true color are parameters commonly used as indicators of the relative concentration of natural organic matter (NOM). UV254, in particular, is used to measure the humic portion of NOM. The primary significance of NOM is as potential precursors to disinfection byproducts (DBP) when combined with a disinfectant such as chlorine; the humic portion of NOM contains the majority of the DBP precursors.

The levels of UV_{254} and true color were low, with no apparent difference between the feed water and treated water.

4.2.2.3 Microbiological Results

Total coliform, indicator bacteria for potential fecal contamination, and heterotrophic plate count (HPC), a general indicator for total bacterial levels, were sampled five days per week for the test period. A summary of sampling results is presented on Table 4-10.

There were no positive indications for the presence of Total Coliform in either the feed water or treated water.

Two feed water samples and three treated water samples were positive for HPC. United Water Pennsylvania staff were contacted concerning these positive samples. A review of the WTP operating records did not indicate any shutdown of the SHG or its metering pumps at the time of HPC sampling. There is also no indication in the ETV field logbook of any shutdown of the disinfection system. The most likely cause of the HPC positives is improper sampling technique, i.e. contaminating the mouth of the sample bottles, perhaps through contact with the sampler's hands.

Table 4-10. Daily(1) Bacteria – Laboratory Analyses

	Feed Water		Treated Water	
	Total Coliform (mpn/100 ml)	HPC (cfu/ml)	Total Coliform (mpn/100 ml)	HPC (cfu/ml)
Mean	<1	4	<1	7
Minimum	<1	0	<1	0
Maximum	<1	73	<1	71
Standard Deviation	0	16.5	0	19.9
95% Confidence Interval	N/A	4 ± 7.6	N/A	7 ± 9.2

"<1" assigned a value of zero for purposes of statistical calculations.
(1)Samples collected 5 days per week.

4.2.2.4 Disinfectant Byproducts

Organic and inorganic disinfectant byproducts are presented on Table 4-11 and Table 4-12.

Table 4-11. Organic Disinfectant Byproduct Analyses

Parameter	Feed Water (mg/l)	Treated Water (mg/l)
TTHM - Inst.	0.0140	0.0160
HAA5 – Inst.	0.0060	0.0187
TTHM – SDS	NT	0.0390
HAA5 – SDS	NT	0.0277

Inst.=Instantaneous
SDS=Simulated Distribution System
NT=Not Tested

Table 4-12. Inorganic Disinfectant Byproduct Analyses

Parameter	Feed Water (mg/l)	Treated Water (mg/l)
Chlorite-Inst.	<0.02	<0.02
Chlorate-Inst.	0.081	0.112
Chlorite-SDS	NT	<0.02
Chlorate-SDS	NT	0.262

Inst.=Instantaneous
SDS=Simulated Distribution System
NT=Not Tested

As indicated on Table 4-11, instantaneous analyses were conducted on both the feed water and treated water samples for TTHM and HAA5. DBP levels were anticipated to be higher in the treated water relative to the feed water due to the addition of post sodium hypochlorite and the additional contact time in the WTP finished water storage. As expected, TTHM and HAA5 levels were higher in the treated water TTHM levels increased slightly, whereas HAA5 levels increased by a factor of three.

A portion of the treated water sample was subject to UFC, as defined under the EPA Information Collection Rule, for the purpose of producing SDS samples under equivalent conditions. These conditions resulted in a three-fold increase in TTHM and 30 percent increase in HAA5.

Table 4-12 presents the results for the inorganic DBP analyses, chlorite and chlorate. As with the organic DBP, instantaneous samples were collected for the feed and treated water. The promulgated D/DBPR has an MCL of 0.8 mg/l for chlorite. Chlorite was not detected in either sample. Chlorate was detected in both the feed water and treated water. SDS conditions resulted in a doubling of the instantaneous chlorate level to 0.262 mg/l. There are presently no proposed regulations for chlorate.

Actual SDS conditions that occurred during the testing are presented on Table 4-13.

The pH values are outside the UFC pH range due to poor buffering (low alkalinity) in the treated water. Before the start of the incubation period, each bottle was adjusted to a pH of 8.0 with caustic soda.

Table 4-13. Simulated Distribution System Test Conditions

Incubation Bottle No.	Incubation Time (hrs)	Chlorine Dose (mg/l)	Chlorine Residual (mg/l)	Temperature (°C)	pH
1	24	0.0	0.64	20.8	7.6
2	24	0.3	0.95	20.8	7.6
3	24	0.6	0.82	20.7	7.3

Another disinfectant byproduct of ongoing concern with the use of on-site generation of sodium hypochlorite is bromate. Bromate will be regulated under Stage 1 of the D/DBPR with an MCL of 0.01 mg/l.

Although the ETV protocol did not require analysis of bromate, bromide, the precursor of bromate, was required. No bromide was detected in either the feed water or treated water, or in the chemical analysis of the sodium chloride used.

4.2.3 Task 3: Data Management

All on-site operating data other than chlorine analyses was entered into the field logbook daily; chlorine analyses were analyzed and recorded twice daily.

Most corrections to logbook errors were made properly by first drawing one line through the error and initializing beside it. Some errors had more than one line drawn through them. There were a few data errors that had a line drawn through them but were not initialized.

Data were entered into summary spreadsheets once a week by the designated United Water Pennsyvania field testing operator. The spreadsheets were printed and checked versus the logbook, but were not initialized by the field testing operator. The spreadsheets were either emailed or faxed to Gannett Fleming. Gannett Fleming performed a check of all data collected in the logbook and entered into the spreadsheets. Incorrect data in the spreadsheets were corrected.

4.2.4 Task 4: Quality Assurance/Quality Control (QA/QC)

4.2.4.1 Turbidimeters

The treated water on-line turbidimeter sample flow rate was checked daily. The average sample flow rate was 380 ml/min, within the manufacturer's specified range of 250 to 750 ml/min. Six sample flow rate checks were less than 250 ml/min.

All on-line turbidimeter readings were checked twice daily versus bench turbidimeter readings of grab sample. The average feed water bench turbidity readings were 0.07 NTU, 14% greater than the on-line readings (0.06 NTU); this may have been due the bench turbidimeter cuvette glass contributing to the turbidity readings.

The treated water grab and on-line turbidity readings, although not always identical, had the same average and standard deviation.

4.2.4.2 pH Meters

The on-line treated water pH meter was compared with a bench pH meter that was calibrated daily. There was a one percent difference in the average readings between these instruments.

4.2.4.3 Chlorine Residual Analyzers

The sample water for the on-line analyzer filled a container in a batch operation; there was no sample flow rate to check.

Readings from the on-line analyzers were checked twice daily versus bench chlorine analyses. For the treated water the on-line readings on average were 8% less than the bench analyses for the treated water.

Two methods of chlorine analysis, SM 4500 Cl-B and SM 4500 Cl-F, were used to analyze the hypochlorite stream for total chlorine. Using SM 4500-Cl F, the average total chlorine residual was 1% higher than with SM 4500-Cl B; the standard deviation SM 4500-Cl F was greater than with SM 4500-Cl B. This possibly indicates that SM 4500-Cl F may be more prone to error by the analyst than SM 4500-Cl B.

4.2.4.4 Generator Dilution Water Flow Meters

The two flow meters were not checked for calibration using the "bucket and stopwatch" method due to difficulties in "breaking" the plumbing; the readings from these meters averaged within 3% of each other, which provided a level of confidence in the accuracy of their readings.

4.2.4.5 WTP Flow Meters

Copies of certificates of calibration for the WTP flow meters are found in Appendix C. A comparison of flow readings for the sum of the four filter flow meters and the finished water flow meter is presented in Appendix C. There is not always close agreement between these two readings because the actual flows pumped from the finished water tanks relative to the flows into the tanks was not always the same.

4.2.4.6 Microbac Laboratories

All Microbac Laboratories analyses followed either *Standard Methods for the Examination of Water and Waste Water*, 18th or 19th Edition (1992, 1995) or *Methods for Chemical Analysis of Water and Wastes* (1979) for sample collection, preservation, hold time and analytical methodology.

4.2.4.7 On-Site Inspection

Ms. Carol Becker of NSF International performed an inspection of the Gannett Fleming ETV program at Hummelstown, Pennsylvania on March 15, 2000. Several corrective actions were discussed during the inspection and implemented as a result of the inspection.

4.3 System Operation

The SHG batch mode of operation was effectively controlled by the sodium hypochlorite storage tank levels together with the PLC. When the liquid level dropped to the low level setpoint, the SHG system was activated from standby mode to generate sodium hypochlorite. When the liquid level rose to the high level setpoint, the SHG was deactivated, returning to standby mode.

The number of SHG continuous hours of operation was contingent on the raw water quality and the WTP production, and varied from 3 hours to 25 hours with an average of 13 hours. The hypochlorite metering pumps typically had to be adjusted manually several times daily to account for these operating variables (there was no pacing system for the metering pumps).

The brine day tank was filled with 30% brine from the saturator tank in a batch mode of operation. The day tank has a level transmitter that relays a 4-20 mA signal back to the PLC, which converts the signal into a continuous reading of brine depth. This level was compared to operator entered high and low day tank level setpoints. When the liquid level dropped to the low level setpoint, the PLC controller activated the solenoid valve on the influent line to open, allowing the brine to flow into the day tank. When the brine level in the day tank rose to the high level setpoint, the PLC controller deactivated the solenoid valve, stopping the flow of brine from the saturator tank into the day tank.

A level probe system on the brine bulk saturator tank would normally maintain a water level that at all times is contained within a heated/insulated portion of the tank, and above the normal level probe. This assures that 30% brine concentration is maintained, the maximum solubility of sodium chloride when the dilution temperature is maintained above 50°F. This system was not operational during the ETV; the saturator tank had to be resupplied with softened water by manually opening a 3-way ball valve to bypass the solenoid and motor-operated valves.

No adjustments were made to the SHG dilution water flow, voltage or amperage during the ETV because these parameters and the brine specific gravity were within the ranges specified in the *ClorTec MC Operator Interface PLC Manual*.

It is stated in the *ClorTec MC Operator Interface PLC Manual* that the bellows pump is factory set. Therefore, no attempts were made to adjust the rate of this pump.

None of the safety lock-out features were tested since the FTO did not want to interfere with normal WTP operations.

4.4 Maintenance

There were a few items that required maintenance during the ETV, none of which directly involved the ClorTec MC 100 system:

- One of the two ion exchange (softener) cylinders developed a leak and was promptly replaced by the manufacturer.
- The one inch feed line (black plastic) on the pre-hypochlorite metering pump developed a pin hole leak.
- The treated water on-line pH probe required replacement.

The hypochlorite generator electrodes had started to develop a scale formation by the end of the 30-day test; scaling had not developed to the point of loss in generator efficiency, requiring acid cleaning. (A loss in generator efficiency becomes evident when an increase in power is required to maintain the same level of concentrated chlorine).

4.5 O&M Manual Review

The *ClorTec MC Operator Interface PLC Manual* was generally well organized. However, there were inconsistencies and deficiencies found in different sections of the manual.

There is not a good explanation for what SHG equipment adjustments need to be made when the hypochlorite concentrate stream is outside the target production concentration of 0.8% ± 0.05% as chlorine. In Section 5 of the manual, MC System Startup, step 10 states that the Model MC 100 dilution water meter should be set at 1.0 gpm. Step 12 states that a sample should be collected from the one inch product line to confirm the brine's density, which should be approximately 1.023 to 1.025. There is no discussion in this section or in the troubleshooting section, Section 7, on what adjustments need to be made if the specific gravity or diluted sodium chloride concentrations are outside of their target ranges, or if the concentrated hypochlorite stream is not within ClorTec's stated performance claims.

In Section 4 under "Brine Tank", item 2, "a consistent 0.3% brine solution" is assumed to be incorrect, and should read "a consistent 3.0% brine solution".

In Section 4 under "Plumbing", the second paragraph states that "the one inch union at the top of the last cell carries the 0.8% sodium hypochlorite product and hydrogen byproduct". The ClorTec Model MC 100 installation at the Hummelstown WTP had two lines connected on top of the last cell, one dedicated for sodium hypochlorite transfer to storage tanks, and the other for the venting of hydrogen outside the building.

In Section 2 under "Brine Saturator Tank", it states that the ClorTec MC Series system uses a 2,000 pound capacity H.D.P.E. salt brine storage tank, with the brine made up via the water float valve positioned within a 6-inch protective chase allowing softened water to fill the tank. The Hummelstown installation has separate tanks for brine generation and brine storage, and level probe and level transmitter systems together with the PLC for controlling water supply influent valves.

4.5 Costs

The *ClorTec MC Operator Interface Manual* states that the ClorTec process requires 3.5 pounds of salt, 15 gallons of water and 2.5 kWh of electrical power to produce one pound of chlorine equivalent. The following table presents the costs associated with each of these feedstock components.

Table 4-14. On-Site SHG Feedstock Costs

Component	Unit Cost*	Total Cost
3.5 lbs of salt	$0.024/lb	$0.084
2.5 kWh	$0.074/kWh	$0.185
15 gallons potable water	$0.0027/gal	$0.041
	1.0 Lb. Cl_2	$0.310

The table below presents a relative chemical cost comparison between liquid gas chlorine, sodium hypochlorite delivered and on-site generated sodium hypochlorite.

Table 4-15. Chlorine Cost Comparison

One Lb Chlorine Chemical Costs	Unit Cost*
Liquid chlorine gas	$0.32/lb
Sodium Hypochlorite (bulk-15%)	$0.90/lb
On-site Sodium Hypochlorite Gen.	$0.31/15 gal.

*Costs from slide presentation by Timothy McGarvey of United Water Pennsylvania and Chester Parks of CP Equipment Sales to AWWA-Pennsylvania Section Conference.

Chapter 5
References

The following references were used in the preparation of this report:

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