Water Research Foundation
advancing the science of water

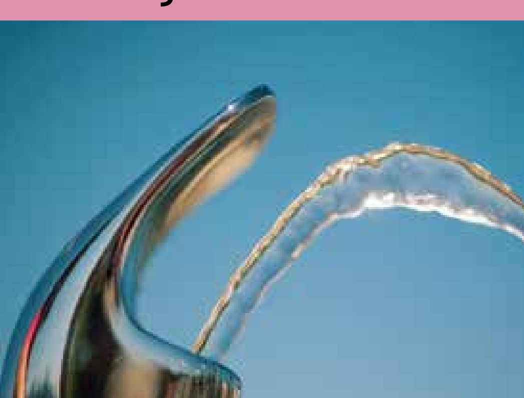
EPA

WERF
Water Environment Research Foundation
Collaboration. Innovation. Results.

Reducing Volatile Disinfection By-Products in Treated Drinking Water Using Aeration Technologies

Web Report #4441

Subject Area: Water Quality




Reducing Volatile Disinfection By-Products in Treated Drinking Water Using Aeration Technologies

About the Water Research Foundation

The Water Research Foundation (WRF) is a member-supported, international, 501(c)3 nonprofit organization that sponsors research that enables water utilities, public health agencies, and other professionals to provide safe and affordable drinking water to consumers.

WRF's mission is to advance the science of water to improve the quality of life. To achieve this mission, WRF sponsors studies on all aspects of drinking water, including resources, treatment, and distribution. Nearly 1,000 water utilities, consulting firms, and manufacturers in North America and abroad contribute subscription payments to support WRF's work. Additional funding comes from collaborative partnerships with other national and international organizations and the U.S. federal government, allowing for resources to be leveraged, expertise to be shared, and broad-based knowledge to be developed and disseminated.

From its headquarters in Denver, Colorado, WRF's staff directs and supports the efforts of more than 800 volunteers who serve on the board of trustees and various committees. These volunteers represent many facets of the water industry, and contribute their expertise to select and monitor research studies that benefit the entire drinking water community.

Research results are disseminated through a number of channels, including reports, the Website, Webcasts, workshops, and periodicals.

WRF serves as a cooperative program providing subscribers the opportunity to pool their resources and build upon each other's expertise. By applying WRF research findings, subscribers can save substantial costs and stay on the leading edge of drinking water science and technology. Since its inception, WRF has supplied the water community with more than $460 million in applied research value.

More information about WRF and how to become a subscriber is available at www.WaterRF.org.

Reducing Volatile Disinfection By-Products in Treated Drinking Water Using Aeration Technologies

Prepared by:
Amlan Ghosh, Chad Seidel, and Eli Townsend
Corona Environmental Consulting, LLC, 357 South McCaslin Blvd., Suite 200, Louisville, CO 80027

Rocio Pacheco
Jacobs Engineering Group, 1999 Bryan Street, Suite 1200, Dallas, TX 75201

Chris Corwin
University of Colorado at Boulder, Department of Civil, Environmental, and Architectural Engineering, Boulder, CO 80309

Jointly sponsored by:
Water Research Foundation
6666 West Quincy Avenue, Denver, CO 80235

Water Environment Research Foundation
635 Slaters Lane, Ste. G-110, Alexandria, VA 22314

and

U.S. Environmental Protection Agency
Washington, D.C.

Published by:

Water Research Foundation℠

DISCLAIMER

This study was jointly funded by the Water Research Foundation (WRF), the U.S. Environmental Protection Agency (EPA), and the Water Environment Research Foundation (WERF) under Cooperative Agreement No. CR-83419201. WRF, EPA, and WERF assume no responsibility for the content of the research study reported in this publication or for the opinions or statements of fact expressed in the report. The mention of trade names for commercial products does not represent or imply the approval or endorsement of WRF, EPA, and WERF. This report is presented solely for informational purposes.

Printed in the U.S.A.

CONTENTS

TABLES

FIGURES

FOREWORD

The Water Research Foundation (WRF) is a nonprofit corporation dedicated to the development and implementation of scientifically sound research designed to help drinking water utilities respond to regulatory requirements and address high-priority concerns. WRF's research agenda is developed through a process of consultation with WRF subscribers and other drinking water professionals. WRF's Board of Trustees and other professional volunteers help prioritize and select research projects for funding based upon current and future industry needs, applicability, and past work. WRF sponsors research projects through the Focus Area, Emerging Opportunities, and Tailored Collaboration programs, as well as various joint research efforts with organizations such as the U.S. Environmental Protection Agency and the U.S. Bureau of Reclamation.

This publication is a result of a research project fully funded or funded in part by WRF subscribers. WRF's subscription program provides a cost-effective and collaborative method for funding research in the public interest. The research investment that underpins this report will intrinsically increase in value as the findings are applied in communities throughout the world. WRF research projects are managed closely from their inception to the final report by the staff and a large cadre of volunteers who willingly contribute their time and expertise. WRF provides planning, management, and technical oversight and awards contracts to other institutions such as water utilities, universities, and engineering firms to conduct the research.

A broad spectrum of water supply issues is addressed by WRF's research agenda, including resources, treatment and operations, distribution and storage, water quality and analysis, toxicology, economics, and management. The ultimate purpose of the coordinated effort is to assist water suppliers to provide a reliable supply of safe and affordable drinking water to consumers. The true benefits of WRF's research are realized when the results are implemented at the utility level. WRF's staff and Board of Trustees are pleased to offer this publication as a contribution toward that end.

Denise L. Kruger
Chair, Board of Trustees
Water Research Foundation

Robert C. Renner, P.E.
Executive Director
Water Research Foundation

ACKNOWLEDGMENTS

This project was a collaborative effort and relied on many individuals to be successful. The project team would especially like to recognize personnel at the OTOE Missouria Tribe Water Treatment Plant including Richmond Grass, Katie Mondallo, and Anderson Berryhill for assistance with demonstration test equipment installation, equipment maintenance, sample collection, and analyses.

The authors would like to recognize Steve Acquafredda (formerly with Jacobs Engineering Group), Dusan Stanisic (formerly with Jacobs Engineering Group), Glen Roth and Doug Smith (Jacobs Engineering Group), Harold Reed (formerly with American Water) for their efforts during utility selection, equipment design, and installation processes.

We acknowledge the contribution from all the equipment providers including Aqua Aerobics Systems, Inc., PAX Water Technologies™, Aqua Metrology Systems, and Parker Hannifin Corporation. Without generous contributions by these equipment providers, demonstration testing and THM data collection would not have been possible. Assistance from Oklahoma Department of Environmental Quality was essential in developing the design report and procuring the construction permit for this project. Finally, the equipment installation and demonstration testing would not have been possible without the assistance of Haynes Equipment and Midco Diving and Marine Services.

We thank the Foundation Research Manager Kenan Ozekin, and the Project Advisory Committee – Jonathan Pressman, Jatin Mistry, Bob Raczko, Mao Fang, and Robert Praga for their support at all stages of this project.

EXECUTIVE SUMMARY

BACKGROUND

Aeration literature and research on total trihalomethane (TTHM) reduction became prevalent following establishment of the 1979 TTHM Rule. The subsequent Stage 1 Disinfectants and Disinfection By-products Rule (DBPR) focused more on DBP precursor removal and changes in disinfection practices. The Stage 2 DBPR, however, with compliance requirements of maintaining TTHM concentrations below 80 µg/L on a locational running annual average (LRAA) basis, has brought aeration back into the forefront as a method to achieve TTHM compliance. For systems with only TTHM concerns and no compliance issues with the five haloacetic acid (HAA5) concentrations, aeration can be an attractive solution. It has lower capital and operating costs compared to most precursor removal processes or alternative disinfectants, which present their own operational costs and challenges. In many cases, TTHM aeration can be used at remote locations in the distribution system to treat only the fraction of water requiring TTHM reduction for LRAA compliance, further reducing costs.

The TTHM requirements of the Stage 2 DBPR have been especially problematic for the southern United States (EPA Region 6), where elevated summer temperatures drive the TTHM formation reaction between chlorine and DBP precursors. Small systems with limited operations budgets and public pressure to keep water rates low can be particularly challenged by TTHM requirements. This is especially true on the outskirts of the distribution system or consecutive systems with high water age.

Among the various aeration technologies available, spray and surface aeration systems have proven to be among the most effective, lowest cost, and most energy-efficient technologies. The recommended aeration approach for a system is dependent upon the source water quality, infrastructure type, and operations characteristics.

While aeration is a relatively straightforward technology to evaluate, implement, and operate, there are still some unresolved issues related to aeration that require further research:

- Comparison of TTHM aeration strategies: The advantages and disadvantages associated with spray and surface aeration strategies need to be determined in order to help small systems identify the best solution without having to perform onsite testing and evaluation.
- Capital, Operational, and Life Cycle Costs: A range and breakdown of capital costs for aeration system installation needs to be developed. Suppliers provide the cost for purchase and installation of their equipment. However, costs for reservoir modifications/rehabilitation, structural improvements, and electrical installation are usually not included in supplier estimates, making it difficult for small systems to plan for the cost of implementing TTHM aeration strategies. Additionally, energy use, equipment repairs, and utility labor need to be quantified so that small systems can develop an estimate of the life cycle costs of the aeration system.
- Impact of active air ventilation on the effectiveness of aeration strategies: Data from full-scale tests has shown that when active ventilation systems are turned off, the aeration systems for TTHM reduction perform poorly. The air flow rate achieved by active ventilation is dependent upon the degree of plugging of the associated intake air

filters. More data showing how air flow rates and ventilation system sizing impact the performance of various aeration strategies is needed.

- The impact of TTHM aeration on distribution system water stability: THM aeration can potentially have unintended negative consequences on distribution system water stability that must be investigated. During the aeration process, the water will quickly establish equilibrium with atmospheric carbon dioxide. This change to the carbonate system can affect pH, the Langlier Saturation Index (LSI), and the calcium carbonate precipitation potential (CCPP). While these changes should be described by available water chemistry models, their accuracy has not been demonstrated to date.

OBJECTIVES

The primary objective of this project was to evaluate cost-effective aeration technology solutions to address TTHM compliance at a water treatment plant clearwell. The project team worked closely with EPA Region 6 and the EPA Office of Research and Development (ORD) to identify a water utility system with known TTHM MCL exceedances that lacked the technical expertise or financial ability to address the problem. Source water quality, infrastructure type, and operations characteristics were evaluated to identify a system for comparable aeration evaluation and testing.

APPROACH

This project investigated the rate of formation of DBPs through the clearwell to assess the effectiveness of reducing TTHMs and evaluated multiple aeration technologies. Surface and spray aeration were studied side by side.

Task 1 – Utility Selection and Aeration System Design

As part of the utility selection task, more than 60 water utilities in Oklahoma with historical TTHM MCL exceedances were evaluated. The key criteria in the selection included clearwell requirements, specific site requirements, location of the utility, and willingness of the utility to participate in the project. Based on an extensive evaluation, the OTOE – Missouria Tribe (OMT) water treatment plant (WTP), located near Red Rock, OK, with a 20,000 gallon steel-welded clearwell, was selected for the site of the demonstration testing.

Once the utility was selected, the project team coordinated with the Oklahoma Department of Environmental Quality (ODEQ) to design the aeration systems and obtain the necessary permits for construction. A two-horsepower (hp) surface aeration system, a three-hp spray aeration system, a mixer, and a ventilation fan system were designed. Additionally, two separate field TTHM measurement instruments were incorporated into the design and construction. The final Engineering Design Report (EDR) was submitted to ODEQ in August 2014, and approval of permit to construct was received from ODEQ in October 2014. Equipment installation was performed on-site in November 2014.

Task 2 – Demonstration Testing

The demonstration testing was conducted for ten weeks between November 2014 and January 2015. Seven conditions were tested during this period including:

- Baseline
- Mixer only
- Ventilation only
- Surface aeration with active ventilation
- Surface aeration with passive ventilation
- Spray aeration with active ventilation
- Spray aeration with passive ventilation

Each condition was tested for at least a one-week duration, with some conditions repeated for a few more days. Given the small volume of the tank, representative operating conditions and water quality could be established in a relatively small amount of time (4 – 6 hours when WTP was operational), and it allowed testing of different conditions with little transition time. Baseline conditions were simulated both at the beginning and at the end of the testing period. A detailed sampling plan was developed prior to the testing period, and sampling and analyses were conducted every day throughout the duration of the testing according to the sampling plan. Samples were collected from the raw water, the WTP effluent, and the clearwell effluent.

Task 3 – Recommendation

Based on the data obtained from the first two tasks and the project team's previous experience, recommendations were developed for understanding elevated TTHM issues, determining the appropriateness of aeration technologies for TTHM reduction, evaluating site characteristics and constraints, and selecting the appropriate aeration system. Key design parameters for the selected aeration system were also summarized. The utility selection and demonstration testing were conducted at a small utility, therefore this report is useful primarily to small water utilities.

RESULTS/CONCLUSIONS

Demonstration testing of the aeration technologies yielded the following conclusions:

- Both surface and spray aeration systems were able to achieve between 19 and 34% TTHM removal in the OMT WTP clearwell. The actual removal of TTHMs was lower than the 50 – 60% TTHM removal predicted from these aeration systems during the development of the EDR. The difference in TTHM removal efficiencies was primarily due to the lower water temperatures (as low as 6°C) experienced during demonstration testing compared to the water temperatures (greater than 15°C) anticipated during development of the EDR.
- It is important to distinguish between TTHM removal by aeration technologies and overall TTHM reduction through the clearwell. The overall TTHM reduction through the clearwell is influenced by multiple factors including variation of hydraulic residence times in the clearwell, formation of TTHMs within the clearwell, and dilution of aeration-treated water with fresh water pumped by the WTP. As such, the overall TTHM reduction through the clearwell was lower than the TTHM removal by the aeration systems.

- Between the surface aeration and the spray aeration systems, the TTHM removal efficiency of the spray aeration system was marginally better (approximately 5% under similar test conditions).
- For both the surface aeration and spray aeration systems, TTHM removal efficiencies improved marginally with the active ventilation. In general, TTHM removal efficiencies were 2 to 4% higher with active ventilation compared to passive ventilation for both surface and spray aeration systems.
- The mixer and the ventilation system by themselves did not show appreciable TTHM removal.
- The most important lesson learned through the demonstration testing is that for the OMT WTP clearwell, the hydraulic residence time is the primary controlling parameter in determining overall TTHM reduction. During daytime hours, when both the WTP and the high-service pumps were operational either continuously or intermittently, the average hydraulic residence time within the clearwell could be as low as two hours, and within that time no TTHM reduction was observed. Conversely, when there was no water flowing in or out of the clearwell during overnight hours, the clearwell behaved like a batch reactor, and higher TTHM reduction was observed.
- From the demonstration testing results, it is evident that implementation of aeration technologies within the OMT WTP clearwell will not be sufficient to lower distribution system TTHM concentrations below MCL levels. While aeration technologies can assist in TTHM reduction, other process improvements within the WTP will be necessary to manage distribution system TTHM concentrations.
- An important factor during the design and implementation of aeration systems in WTP clearwells is CT impacts. Any aeration system is likely to mix the water in the reservoir such that the baffling factor will be reduced. If CT credits are being claimed through the reservoir, it is important to take the reduction of baffling factor into consideration, and ensure that sufficient CT is still achieved with the aeration system in place.
- Evaluation of the field TTHM analytical instruments demonstrated that these instruments are easy to install and operate, can generate TTHM results quickly, and most importantly are accurate and precise (i.e., within ±10% of laboratory results).

APPLICATIONS/RECOMMENDATIONS

Aeration technologies have become increasingly popular in recent times for the mitigation of high TTHMs in the distribution system due to a number of factors. Aeration technologies are not capital-intensive to implement, they are easy to operate and maintain, require minimal or no footprint for installation, and do not generate any residuals. While aeration technologies can be a very cost-effective treatment alternative for high TTHM mitigation, they are not appropriate for application in all high TTHM situations. Secondly, even if aeration technologies were appropriate for a particular scenario, additional evaluations are necessary to determine the most appropriate type and design of aeration system that should be selected and implemented. A step-by-step process needs to be adopted to determine the appropriateness of aeration technologies, and selection of the suitable aeration type and design. The key factors in the evaluation of aeration technologies include:

- Understanding the extent of the DBP problem

- Evaluation of the treatment site, including the reservoir design
- Selection of the appropriate aeration technology
- Design of the aeration technology

Based upon the demonstration testing results, best practices were developed for understanding elevated TTHM issues (e.g., influence of water temperature), evaluation of treatment site and reservoir constraints (e.g., influence of clearwell hydraulic residence time), and selection of the appropriate aeration technology and design of the aeration system (e.g., surface aeration versus spray aeration, with or without active ventilation, etc.). These recommendations were based upon the observations and conclusions made through the utility selection and demonstration testing, as well as the project team's previous experience designing aeration systems at facilities of similar size and with similar water quality characteristics. While the best practices mentioned in this report can serve as general guidelines, it should be emphasized that a site-specific evaluation is critical prior to the selection, implementation, and operation of an aeration system for optimal TTHM removal performance.

RESEARCH PARTNERS

- U.S. Environmental Protection Agency
- Water Environment Research Foundation

PARTICIPANTS

- OTOE-Missouria Tribe
- Aqua Aerobics Systems, Inc.
- Aqua Metrology Systems
- BETE Fog Nozzle, Inc.
- PAX Water Technologies™
- Parker Hannifin Corporation
- Oklahoma Department of Environmental Quality

CHAPTER 1
INTRODUCTION AND PROJECT BACKGROUND

INTRODUCTION

The use of chlorine as a primary and secondary disinfectant is widely implemented and generally accepted as an efficient and cost-effective disinfection strategy. Pathogenic microorganisms are the target contaminant of disinfection with chlorine; however, when using chlorine as a disinfectant an unintended consequence occurs. Dissolved organics frequently persist through conventional treatment at low levels and tend to react with chlorine during disinfection to form disinfection by-products (DBPs). DBPs are regulated in two categories, total trihalomethanes (TTHM) and five haloacetic acids (HAA5).

There are a number of current control strategies approved by the United States Environmental Protection Agency (EPA) for DBP mitigation. In bulk, there are three forms of mitigation strategies; (1) remove precursory compounds found in fresh water sources; (2) use alternative disinfectants such as chloramines that do not form (as much) DBPs; (3) remove DBPs after formation. The aim of this study is to focus on the latter of these two strategies; mitigate DBPs after formation.

In 1998, the Stage 1 DBP Rule (DBPR) was published by the EPA to require minimum residual disinfectant levels and propose maximum contaminant level goals (MCLGs) for trihalomethanes, haloacetic acids, chlorite, and bromate. Chlorite and bromate are formed from using alternate forms of chemical disinfection such as chlorine dioxide and ozone. MCLGs are non-enforceable standards that are often lower than the enforceable maximum contaminant level (MCL) and represent the theoretical lowest attainable post-treatment concentration. MCLs must be met as an average across all sample locations within the distribution system. In 2006 the EPA published the Stage 2 DBPR requiring that the MCLs be met at every sample location in the distribution system as opposed to an average across all sample points within the distribution system.

The Stage 2 DBPR established compliance requirements of maintaining TTHM concentrations below 80 µg/L on a locational running annual average (LRAA) basis. This brought back focus on treatment technologies that can remove TTHMs at localized areas in the distribution system as an effective technology for maintaining TTHM compliance. The Stage 1 DBPR resulted in most systems investigating the low-cost DBP solutions such as lowering chlorine dose, minimizing formation time, enhanced coagulation, and filtration. For systems that have evaluated the above alternatives but are still faced with Stage 2 DBPR compliance issues, their two options for treatment are precursor removal, measured by total organic carbon (TOC) removal; or DBP removal after formation through disinfection or pre-oxidation processes.

Treatment Technologies

For systems with high TTHM occurrences and no compliance issues with HAA5, aeration can be an attractive solution because it has both lower capital and operating costs when compared to most precursor removal processes (enhanced coagulation, activated carbon, ion exchange, high-pressure membranes, etc.). Additionally, in many cases TTHM aeration can be installed at various remote locations in the distribution system, treating only the fraction of water requiring TTHM removal for LRAA compliance, further reducing costs.

Alternative disinfectants and pre-oxidants are frequently used for lowering DBP formation in treated water. When HAA5s are not of concern, switching primary disinfectants to ozone, chlorine dioxide, or UV light can all assist with TTHM reduction. In the distribution system, the secondary disinfectant can be switched to combined chlorine (chloramines) instead of free chlorine. However, switching disinfectant type can present different operational costs and new challenges. For example, ozone can react with naturally occurring bromide in the water to form the regulated DBP bromate.

Coagulation is a unit process commonly used to meet the Stage 2 DBPR by removing precursory compounds. Historically, coagulation is installed prior to filtration for particle removal leading to prolonged filter run-times. Since the determination of the Stage 2 DBPR, utilities and researchers have implemented enhanced coagulation (EC), focusing on TOC along with particle removals. However, for the dual purpose of removing total organic carbon (TOC) and particulates, a higher coagulant dose and depressed pH are frequently needed. The EPA has researched EC for decades determining the effectiveness for removing DBP precursors and particles and exploring long-term reliability and application of this process (EPA 1988). EC is targeted at removing highly reactive organics from the raw water prior to chlorination. Aromatic moieties and electron rich structures promote the reactiveness of organics.

It is well researched that aromatic moieties strongly absorb light in the ultra-violet (UV) region (Weishaar et al. 2003). Specific UV Absorbance (SUVA) has been developed to provide a better fundamental understanding and predict coagulation potential of source waters. SUVA is defined as the UV absorbance measured at 254 nm (UVA_{254}) divided by the dissolved organic carbon (DOC) concentration and carries units of L/mg/m. Research has shown then generally, waters with SUVA below 2 L/mg/m are difficult to coagulate (Edzwald and Tobiason 1999). It is of note that the output units of most spectrophotometers is in cm^{-1}. Therefore, the equation above must be multiplied by 100 to convert to the proper SUVA units.

Coupled with EC, the use of filter-adsorber columns packed with granular activated carbon (GAC) has emerged as an attractive technology to comply with the Stage 2 DBPR (EPA 2007). GAC filters are especially effective at removing DBP precursors. GAC filters can operate either as a biological filter, or as a standard filter-adsorber. If it is operated in biological mode, there is no chlorination prior to GAC filtration. This allows microbes to live and thrive on the GAC filters and promote the breakdown of organics, many of which would not have been previously retained on the filter. Chlorine inactivates microorganisms on the GAC media; if this happens, biodegradation does not occur. As such, when GAC filters are operated in biological mode, chlorination is not performed ahead of the filtration process.

Membrane treatment is another, more expensive treatment technology used to remove TTHMs. While membrane treatment may result in increased removal efficiencies, the high pressure required results in a substantial operational cost. The price of membrane operation per gallon of water treated may not be economic for very small systems. Ion exchange is another treatment technology that may be used for DBP mitigation, but the costs associated with residual byproduct management can outweigh any potential benefits.

For systems with high TOC or high occurrences of both HAA5 and TTHM, it may be necessary to use both EC and GAC treatment. Both the long-term reliability and the redundancy of these technologies provides adequate removal of DBP precursors. However, for small systems or systems with elevated TTHM and no HAA5 concern, it may not be economic to use conventional treatment. Instead, focusing on mitigating DBPs after formation may be more feasible and sustainable in the long term.

Aeration Technologies

When HAA5s are not of major concern but TTHMs are, aeration technologies can be more cost-effective than conventional treatment. TTHMs are more volatile than HAA5s, and as such are more amenable to aeration.

Aeration can also be favored over conventional treatment for small systems due in large part to the reduced solids residual formation. Coagulation creates metal hydroxide complexes that settle out in sedimentation and builds up on a filter, creating the need for more frequent backwashing. Following sedimentation, these solids must be removed and disposed of resulting in higher operational costs. Build up on a filter can cause backwashing frequency to increase, resulting in higher operational costs. Minimizing the production of solids and reducing backwash frequency will result in the lowering of operational and maintenance costs.

Henry's Law governs the THM removal process by aeration which dictates the equilibrium concentration of a compound in water in contact with air, or vice-versa. For dilute solutions and low gas pressures, the amount of a given gas dissolved in a given type and volume of liquid is directly proportional to the partial pressure of that gas in equilibrium upon the liquid. In 1803 this law was first formulated by an English physician and chemist William Henry. Henry's law can be applied for a variety of dilute solutions, and is not limited to just gases. In mathematical terms and at a constant temperature:

$$kH,cc = caq/cgas \quad (1)$$

Where $k_{H,cc}$ is the dimensionless Henry's constant, c_{aq} is the concentration of the solute in the aqueous phase, and c_{gas} is the concentration of the solute in the gas phase. Table 1-1 lists the dimensionless Henry's constant values of the four THM species at 20°C and 1 atm pressure (Staudinger and Roberts 1996). As can be seen from the table, chloroform has the highest Henry's constant meaning that it is the most volatile among the four THM species. As the bromine content of THMs increases, the Henry's constant, and correspondingly, the volatility of the compound decreases. Bromoform is the least volatile THM, and its Henry's constant is more than an order of magnitude lower than that of chloroform.

Table 1-1 Henry's constant values for four THM species at 20°C and 1 atm pressure

THM Species	Formula	Dimensionless Henry's Constant (1 atm, 20°C)
Chloroform	$CHCl_3$	0.1500
Bromodichloromethane	$CHCl_2Br$	0.0656
Chlorodibromomethane	$CHClBr_2$	0.0321
Bromoform	$CHBr_3$	0.0219

Source: data from Staudinger and Roberts 1996

There are many variations of aeration as a treatment technology and as a result, many different unit processes may be viable for a given treatment objective. In 1985, Roberts and Levy compared the energy required to operate different aeration strategies for TTHM removal. The energy comparison showed similar effectiveness between the countercurrent packed column and mechanical surface aeration process for air stripping of THMs. Capital investment, operating and maintenance costs other than energy, reliability and land requirements must be considered in process selection. Air pollution control can be attained more effectively with packed towers than with aeration basins, a factor which may influence process selection in regions with air quality problems.

As such, it is vital to explore the aeration variations and select the best one for any given treatment objective though a holistic evaluation. Two types of aeration technologies commonly used in municipal drinking water treatment are spray aeration and surface aeration. There is also diffused aeration, tray aeration, packed tower aeration, and bubble aeration. This report focuses on spray and surface aeration, as they are the most commonly used treatment technologies for TTHM reduction. Bubble aeration has been researched and used, but it was not selected in this project because it has certain limitations which makes it less favorable for this particular application.

Spray Aeration

Spray aeration implements a shower-like faucet in the headspace of a water tank. The water is sprayed out the faucet to create small droplets of water. Surface aeration mimics turbulent surface mixing in practice. Water is rapidly mixed at the surface so that waves, ripples, and bubbles are formed which promote air-water transfer of volatile compounds and oxygen, alike. For TTHM aeration both volatilization and oxidation occur. TTHMs are volatile and it has been reported that up to 99.5% removal of TTHM can be achieved using spray aeration (Brooke and Collins 2011).

Spray Aeration includes a hub-and-lateral piping system with spray nozzles installed at the ceiling of a reservoir. Water entering the reservoir passes through the spray nozzles to form small droplets with high surface area that are sprayed downward into the reservoir. The design parameters that influence TTHM removal efficiency include the number of spray nozzles, water droplet size and air-water contact time. The air-water contact time is dependent on reservoir water level and water droplet velocity. A computer model was used to predict TTHM reduction and energy consumption based on the calculations provided in the AWWA Water Quality and Treatment Handbook (6th edition). Table 1-2 lists the equations used to explain and design spray aeration.

Table 1-2 Equations governing THM removal via spray aeration

Spray Aeration Equations	Parameter	Equation	Units
TTHM Concentration after Spray Aeration	C_e	$C_o \exp(-K_L \alpha t_{Total})$	mg/L
Velocity of Water Leaving Nozzles	v_d	$\frac{Q}{(\pi \cdot \frac{d^2}{4})}$	ft/sec
Contact Time for the Water Droplets with the Air	t	$\frac{\sqrt{(v_d \cdot \sin\alpha)^2 + 2g \cdot H} - v_d \cdot}{g}$	sec
Radius of spray pattern created by each nozzle	R	$\frac{H}{\tan\alpha}$	ft
Area of Influence	A	$\pi \cdot R^2$	ft^2
Maximum Number of Nozzles	$No.N$	$\frac{A_i}{A}$	$Nozzles$
Total Flow Rate that the System can Handle	Q_{Total}	$(No.N) \cdot Q$	gpm
Number of Passes for the Water Entering the Reservoir	$No.P$	$\frac{Q_{Total}}{Q_i}$	$Passes$
Overall Liquid Phase Mass Transfer Coefficient	K_L	$2(\frac{D_l}{\pi \cdot t})^{1/2}$	m/sec
Interfacial Surface Area Available for Mass Transfer	α	$\frac{6}{d_p}$	m^{-1}

C_e : Effluent TTHM concentration;
C_o : Influent TTHM concentration;
K_L : Overall liquid mass transfer coefficient;
α : Interfacial surface area available for mass transfer;
t_{Total} : Total contact time of the water droplets with the air;
v_d : Velocity of water droplets leaving the nozzle;
Q : Volumetric flow through one nozzle;
d : Inner nozzle diameter;
t : Contact time of water droplets with the air;
H : Headspace between the sprayer and the water surface;
g : Gravitational acceleration;
R : Radius of spray influence;
A : Area of spray influence:
A_i : Area in reservoir *i*;
Q_{total} : Total flow rate the spray system can handle;
Q_i : Flow through reservoir i;
D_l : Contaminant (TTHM) liquid diffusivity;
d_p : Sauter mean diameter (SMD) provided by manufacturer

Source: data taken from AWWA 2011a

Spray aeration may require complete reservoir shutdown and water drainage during hub & lateral system installation. The inspection and maintenance work may be considerable depending on the size of the reservoir and the system. Pump maintenance is typically scheduled on a yearly interval and mechanical repairs may require involvement of divers if a submersible pump is used in the reservoir. The hub & lateral system inspection / nozzle replacement is typically scheduled every other year. TTHM removal efficiency decreases with increase in water level; and it may limit maximum water level that the reservoir can be operated to still achieve desired TTHM removal. If divers are not used, reservoir may need to be isolated and drained for hub and lateral pipe system maintenance and nozzle change outs. Spray aeration would provide complete mixing through spraying water onto the water surface and recirculation through the spray system.

Surface Aeration

Surface aeration consists of floating surface aerator(s) installed within the reservoir. The aerator(s) constantly draw in water from a few inches beneath the surface, and spray it laterally through the air. The main parameter that controls TTHM reduction is the power-to-volume (P/V) ratio, that is, the unit power applied by the surface aerator to the water. Surface and diffused aeration are superficially similar in that contacting usually is achieved in open basins and their cost-effectiveness for oxygen transfer is approximately equal. There is direct transfer to the atmospheric boundary layer, which offers a much larger volume and hence a much larger use of energy. Energy is typically input directly into the water surface by means of a rotating turbine agitator. These devices are more common in wastewater applications than drinking water treatment. The oxygen transfer rate constant ($K_L a$) is proportional to the energy input:

$$K_L \alpha = K_p (P/V)$$

Where P = power input in Watts,
V = aeration basin volume (ft^3) and
K_p = proportionality constant with units of $ft^3\ W^{-1}\ s^{-1}$.

More information on the derivations for surface aeration calculations can be found in Roberts and Levy, Energy Requirements for Air Stripping Trihalomethanes (1985). The advantage for surface aeration is the process does not require complete reservoir shutdown and water drainage. The disadvantages of surface aeration consist of the need for a crane to remove and re-install the surface aerators in the reservoir also surface aerator lubrication is recommended every 6 months and there may also be a need to remove/replace equipment regularly. A certain minimum and maximum water level is required for surface aerators to operate properly, and there is a limit on maximum water level of overflow. The reservoir with surface aeration equipment must be isolated but not drained for surface aerator removal and replacement. Overall the surface aeration process will provide near-complete mixing through agitating water by the surface aerators.

Optimization of Aeration Treatment

The fundamentals of aeration provide insight as to how the process can be optimized. Henry's Law dictates equilibrium concentrations of a compound in air and water and in turn, aeration. The basic idea of Henry's Law is that the solubility of a gas is directly proportional to the partial pressure of the gas above the aqueous phase.

There are two ways to enhance transfer of solute from the aqueous to the gas phase. First, if the interface area can increase, then there is more potential for phase transfer. Second is temperature. Temperature affects compounds activity in air and water. Higher temperatures result in higher vapor pressure and in turn, more volatilization (Water → Air). However, changing the surrounding temperature to an aeration system can be energy intensive and not feasible. Instead controlling the surface area of the air: water interface is used to increase aeration efficiency.

Another way to promote transfer of solute from the aqueous to the gaseous phase is by varying the Air: Water ratio (A/W). The idea is that when there is more air in a system than water there is a larger receiving body for the aqueous concentration of a given compound. The ways to change air: water transfer are by changing the temperature, Air: water ratio, the concentration of a compound in either phase, or by increasing the surface area of the air: water interface.

Case Studies and Previous Installations

Application of aeration for TTHM removal is relatively new, but it has been implemented in locations across the United States to varying degrees and in various forms (Clark 2013, Sherant 2008, Reid 2012, Jacobsen et al. 2011, Fiske et al. 2011). Monroe County Water Authority (MCWA) investigated the potential for full scale implementation of spray aeration in Pembroke, NY (Clark 2013). Pembroke has experienced seasonal TTHM differences at the entry point to the distribution system, experiencing high concentrations near 70 µg/L and lows around 20 µg/L since 2006. Pembroke set an internal MCL of 64 ppb (µg/L) which they frequently exceeded. MCWA proceeded to install full scale water spray aeration in their 61-ft tall distribution system storage tank. Reported TTHM removals in this tank were 43% in 2010 and 42% in 2011. When this treatment was implemented system-wide in multiple storage tanks, TTHM removals were observed averaging 51% across the entire distribution system.

Also operated by MCWA, the town of Mendon, NY needed to develop a system that could manage TTHMs in their southeastern portion of an expansion to their distribution system. An aeration system that could remove at least 35% of the influent TTHM concentrations was designed. Different air: water ratios were investigated until the optimal ratio was determined. The existing storage basin was retrofitted with disc and tubular diffusers. An unexpected added benefit of installing diffuser aerators was that in the winter months, ice was not prevalent on the reservoir.

The town of Queensbury, NY performed a study that demonstrated the effectiveness of spray aeration, and subsequently implemented a system that has been in operation since the summer of 2012. During the preliminary stages of this study, a model was developed to predict the percent removal of TTHMs based on droplet diameter (µm) and droplet travel distance (height of fall). This model was appropriately customized for this particular system. For a given droplet diameter, the longer the travel distance is, the higher the removal is of TTHM. Conversely, for a given travel distance, the larger the droplet diameter, the lower the removal is of TTHM. This case study validated one of the concepts believed to be of major importance for aeration - as surface area increases (smaller droplets) the removal of TTHMs increases.

PROJECT BACKGROUND

Aeration literature and research on total trihalomethane (TTHM) reduction was initiated following the establishment of the 1979 TTHM Rule, however, implementation of aeration systems for TTHM removal have only become popular in recent times since the Stage 2 DBP Rule has been in effect. While the subsequent Stage 1 disinfectants and disinfection by-products rule

(DBPR) focused more on DBP precursor removal and changes in disinfection practices, the Stage 2 DBPR, with compliance requirements of maintaining TTHM concentrations below 80 µg/L on a locational running annual average (LRAA) basis, has brought aeration back into the forefront as a method to achieve TTHM compliance. The Stage 1 DBPR resulted in most systems investigating the low-cost DBP solutions such as lowering chlorine dose, minimizing formation time, and enhanced coagulation. Thus, for systems now faced with Stage 2 DBPR compliance issues, their two options are most likely precursor removal, measured by total organic carbon (TOC) reduction; or DBP removal after formation. For systems with only TTHM concerns and no compliance issues with HAA5 concentrations, aeration can be an attractive solution because it has both lower capital and operating costs compared to most precursor removal processes (enhanced coagulation, activated carbon, ion exchange, high-pressure membranes), or alternative disinfectants which present their own operational costs and challenges. Additionally, in many cases, TTHM aeration can be used at remote locations in the distribution system treating only the fraction of water requiring TTHM reduction for LRAA compliance, further reducing costs.

The TTHM requirements of the Stage 2 DBPR have been especially problematic for compliance in areas in the southern United States, like EPA Region 6, where elevated summer temperatures drive the TTHM formation reaction between chlorine and DBP precursors. Small systems with limited operations budgets and public pressure to keep water rates low can be particularly challenged by TTHM requirements. This is especially true at locations on the outskirts of the distribution system or consecutive systems where there is high water age. As an example, Figure 1-1 presents the 2012 TTHM MCL violations in EPA Region 6 compiled from EPA Safe Drinking Water Information System (SDWIS) data (EPA 2014).

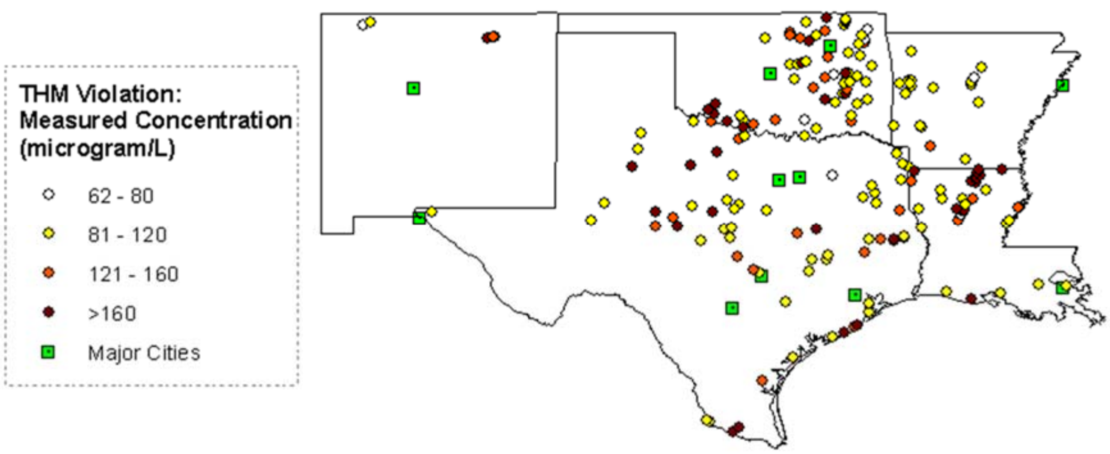


Figure 1-1 2012 TTHM MCL violations in EPA Region 6

Aeration has been demonstrated to have relatively low capital and operations costs compared with other TTHM compliance approaches and can achieve high levels of TTHM reduction. However, all aeration systems are not equally effective for TTHM reduction. Table 1-3 below presents aeration technologies that were evaluated in this project and a brief description of characteristics for TTHM reduction.

Table 1-3 Summary of THM aeration technologies evaluated in this project

Aeration Technology	Description
Technologies evaluated in this project	
Spray Aeration with Ventilation 	Reservoir flow re-circulated through engineered spray nozzles Active air ventilation recommended as part of strategy Calculation tools available to size nozzles and flow rate for TTHM reduction Energy consumption for pumping through spray system becomes important component of annual cost for large reservoirs / clearwells
Surface Aeration with Ventilation 	Floating aeration units supported within reservoir Active air ventilation recommended as part of strategy Calculation tools available to size aerator for target TTHM reduction Technology was identified as a very energy efficient process for TTHM reduction.
Active Ventilation Only 	Supply fan passes filtered air into reservoir which is exhausted through existing vents. Remove TTHMs from the headspace above water surface within the clearwell or reservoir. Modeling estimates indicate less than 10% reduction would be achieved through active ventilation only.
Mixing Only	Many clearwell / reservoir mixing systems are available Mixing systems help to remove dead zones within a reservoir where extended water age leads to increased TTHM formation
Other technologies not evaluated in this project	
Bubble Aeration	Blower used to pass air through diffuser system at bottom of reservoir Calculation tools available to size blower for TTHM reduction Can require significant energy to apply bubbles at bottom of tall water column which is not an energy efficient process for TTHM reduction.
Tray / Packed Tower Aeration	Blower used to pass air countercurrent to water flow through tower system Equipment must be installed external to the reservoir and requires pumping back to water storage Maintenance required to remove scaling

Of the technologies listed in Table 1-3, spray and surface aeration systems have proven to be among the most effective, lowest cost, and most energy efficient technologies. The recommended aeration approach for a system is dependent upon the source water quality, infrastructure type, and operations characteristics.

This project was designed to evaluate a cost effective aeration technology solution to address the formation of DBPs, specifically TTHMs at the treatment plant's clearwell. The project team worked closely with EPA Region 6 and the EPA Office of Research and Development (ORD) to identify a system with known MCL exceedances for TTHMs and that lacked the technical expertise or financial ability to address the problem. Source water quality, infrastructure type, and operations characteristics were evaluated to identify a system for side-by-side testing of different aeration technologies.

Past Research on Aeration Technologies

The following questions have been addressed as part of past research on the effectiveness of aeration technologies for TTHM removal.

- Tools for Sizing Aeration Processes: Tools have been developed to size aeration systems and predict the reduction of contaminants including TTHMs as listed in Table 1-4 below.

Table 1-4 TTHM Aeration Analysis Tools

TTHM Aeration Strategy	Analysis Tool
Spray Aeration	Spreadsheet tool developed based on AWWA Water Quality and Treatment Handbook and research by Brooke and Collins (2011).
Surface, Bubble, and Packed Tower Aeration	Aeration System Analysis Program developed by Michigan Tech (1999)

- Impact on Chlorine Residual: Hypochlorous acid and hypochlorite ion are the predominant chlorine species present in water with pH in the range between 6.5 and 8.5. These compounds are not readily volatile. Full-scale testing has shown very minor loss of chlorine residual with operation of aeration systems so long as the pH of the water was greater than 7 (Hirschhorn and Moore 2014). Some of the early reports of residual loss have later been attributed to temporary conditions where mixing in a tank has entrained sediments that have exerted a high chlorine demand.
- Increasing pH: Data from full scale aeration installations shows a small increase in pH due to simultaneous removal of carbon dioxide with implementation of aeration processes for TTHM reduction (Hirschhorn and Moore 2014).
- Reformation: Since Stage 2 DBPR compliance is based on concentrations at downstream distribution system sites, TTHM reformation is an important consideration. Data was collected from prior aeration installations which indicate that the concentration of TTHMs removed by aeration is approximately maintained over the remainder of the formation potential curve (See TTHM and DBCM removal during aeration and reformation in Figure 1-2 below).
- Reduction of Chlorinated and Brominated TTHMs: The chlorinated TTHMs (chloroform and dichlorobromomethane) are more volatile than the brominated TTHMs (bromoform and dibromochloromethane). Toxicology studies have indicated the brominated TTHMs have higher cancer risk and as result their removal is important. As shown in Figure 1-2 below, data collected from prior aeration demonstration testing (Seidel et al. 2010) confirms that brominated TTHMs are also removed by aeration.

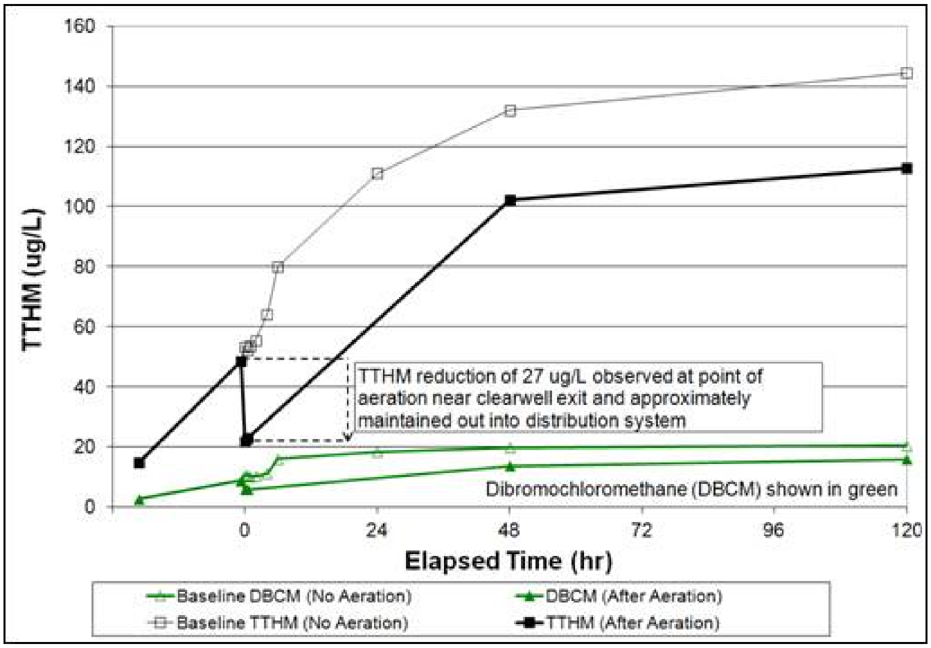


Figure 1-2 TTHM and DBCM removal during aeration and reformation

Research Needs on Effectiveness of Aeration Technologies for TTHM Removal

The following questions regarding the effectiveness of TTHM removal by aeration technologies warrant additional research. This research has specifically addressed comparison of TTHM aeration strategies, and impact of air ventilation on aeration strategies.

- Comparison of TTHM aeration strategies: The advantages and disadvantages associated with spray and surface aeration strategies need to be developed to help small systems identify the best solution without having to perform onsite testing and evaluation.
- Capital Costs: A range and breakdown of capital costs for installation of aeration systems needs to be developed. Suppliers provide the cost for purchase and installation of their equipment. However, costs for reservoir modifications / rehabilitation, structural improvements, and electrical installation are usually not included in supplier estimates making it difficult for small systems to accurately plan for the cost of implementation of TTHM aeration strategies.
- Annual Costs: Annual costs are another important consideration for aeration technology selection. Energy use, equipment repairs, and utility operations staff labor are major components of the annual cost.
- Impact of active air ventilation on the effectiveness of aeration strategies: Data from full-scale tests has shown that when active ventilation systems are turned off, they affect the performance of aeration systems for TTHM reduction. The air flow rate achieved by active ventilation is dependent upon the degree of plugging of their associated intake air filters. Data needs to be obtained to relate air flow rates and ventilation system sizing with performance of aeration strategies for TTHM reduction.

- The impact of TTHM aeration on distribution system water stability: THM aeration can potentially have unintended negative consequences on distribution system water stability that must be investigated. During the aeration process, the water will quickly establish equilibrium with atmospheric carbon dioxide. This change to the carbonate system can affect pH, the Langlier Saturation Index (LSI) and the calcium carbonate precipitation potential (CCPP). While these changes should be able to be described by available water chemistry models, their accuracy has not been demonstrated.

Project Objectives

This primary objective of this project was to evaluate cost effective aeration technology solutions to address TTHM compliance at a WTP clearwell location. The reason for performing this testing at a clearwell vis-à-vis a distribution system reservoir was that, if aeration at the WTP clearwell was able to achieve TTHM MCL compliance, it would be a solution for all (potentially multiple) consecutive systems. The project team worked closely EPA Region 6 and the EPA Office of Research and Development (ORD) to identify a water utility system with known TTHM MCL exceedances, which lacks the technical expertise or financial ability to address the problem. Source water quality, infrastructure type, and operations characteristics were evaluated to identify a system for comparable aeration evaluation and testing.

CHAPTER 2
UTILITY SELECTION AND AERATION EQUIPMENT DESIGN

UTILITY SELECTION

Utility selection was critical to the success of this project. At the outset of the project, it was determined that the full-scale testing would be conducted in a reservoir located at a small, rural or tribal utility with known TTHM exceedances, but no HAA5 exceedances. The utility needed to be located in EPA Region 6, specifically in Oklahoma.

Several other site selection features were identified and prioritized in site selection such that the project scope could be accomplished within the available budget. These are summarized in Table 2-1 and described more fully below.

The first requirement was a utility that would be a willing participant in the project. Utility staff must have availability and be willing to provide sampling support, as well as some basic analytical sampling and analysis support (pH, temp., alkalinity, hardness, etc.). Other requirements of the utility and the clearwell are discussed below.

Existing Reservoir Requirements

If a clearwell were selected, it needed to have excess CT to allow for the addition of mixing without compromising the disinfection process and compliance. A utility with twin clearwells in which each one can provide CT would have been ideal. The ideal reservoir would be of concrete with two sizable hatches to accommodate the installation of mixing and aeration equipment. Concrete construction reduces structural and coating considerations, and below grade concrete locations would allow drive up access to facilitate installation of the aeration systems. If drive up access were not available, the utility needed to have access to a crane to facilitate installation. The reservoir also needed to have adequate venting. The reservoir would be operated at a near constant water level, with enough headroom to the ceiling (> 3 - 4 feet) to incorporate aeration technologies. The ability to provide a reasonably constant flowrate throughout the testing phase would also have been ideal.

Other Requirements

The selected site needed to have an adequate power supply available. The selected utility would be responsible for making the electrical connections for the testing equipment. The plant flow rate and reservoir storage volume impact the size and cost for aeration equipment. A reservoir storage volume less than 2 MG would be most appropriate and ideal for this project. The residence time in the distribution system after the reservoir should be less than about 2 days. Longer formation times require much larger levels of removal of TTHMs and may not be able to meet regulations with even close to 100% TTHM removal. In order to manage travel costs, the selected site should be located within 50 miles of a major airport.

Table 2-1 Utility selection requirements

Utility Requirements:	Reservoir Requirements:	Locational Requirements:
Willing participant Availability for limited sampling and analysis Ability to make electrical connection Equipment to lift aeration equipment and pumps	Excess CT Adequate access Concrete structure Near constant flow level and flow rate Adequate headspace Excess pumping capacity (from high service pumps) 1 – 3 MG	Adequate power supply Access to major airport Limited residence time beyond reservoir

More than 60 utilities were evaluated during the utility selection process. The evaluations were based on utility interest in participating in the study, infrastructure at their water treatment plant and distribution system, clearwell and reservoir configurations, TTHM concentrations at distribution system locations, etc. Site visits were also conducted at multiple utility sites to determine appropriate testing logistics. Based on these evaluations, the OTOE-Missouria Tribe (OMT) Water Treatment Plant (WTP) in Red Rock, OK was selected to be the site for demonstration testing.

OMT WTP

The OMT water treatment plant (WTP) serves a population of approximately 250 and is supplied by raw water via a pipeline from Kaw Lake and Stillwater, OK. The OMT WTP process consists of twin Microfloc® Trimite™ 50 units (Adsorption Clarifier and Mixed Media Filter), with a coagulant/polymer blend and sodium hypochlorite disinfection prior to entering a 20,000 gallon clearwell for storage and disinfection contact time. Treated water is pumped from the clearwell to the OMT distribution system including 110,000 gallon standpipe near the WTP.

The objective of this project was to test surface and spray aeration technologies to reduce TTHM concentrations in the OMT distribution system to levels that are compliant with the Stage 2 DBP Rule (< 80 μg/L LRAA).

The following sections describe the OMT WTP site, the water treatment processes, and the water quality considerations that were included in the evaluation and design of aeration technologies that were subsequently designed, constructed and tested at the WTP site.

Site Description

The WTP and clearwell are located in the vicinity of the intersection of Windmill and Highway 177, near the town of Red Rock, Oklahoma as shown in Figure 2-1.

Figure 2-1 OMT WTP site plan

The WTP operates as needed to maintain storage in the nearby 110,000 gallon standpipe. The WTP site includes the following existing infrastructure.

- Site Building including:
    - Twin Microfloc® Trimite™ 50 units (Adsorption Clarifier and Mixed Media Filter)
    - Coagulant/polymer blend and feed system
    - Sodium hypochlorite disinfection feed system
    - Office and laboratory
- 20,000 gallon steel welded clearwell (12 foot diameter, 24 foot height)
- Two booster pumps with a combined capacity of 80 gpm;
- Valves, piping, and associated appurtenances
- Twin backwash ponds

Microfloc® Trimite™ 50 Units Design

The OMT WTP has two Microfloc® Trimite™ 50 two stage package treatment units. The first stage is an Adsorption Clarifier designed for turbidity removal, followed by the second stage that is a Mixed Media Filter. Each of the two package units has a design capacity of 50 gpm. Figure 2-2 shows a schematic of the package treatment unit.

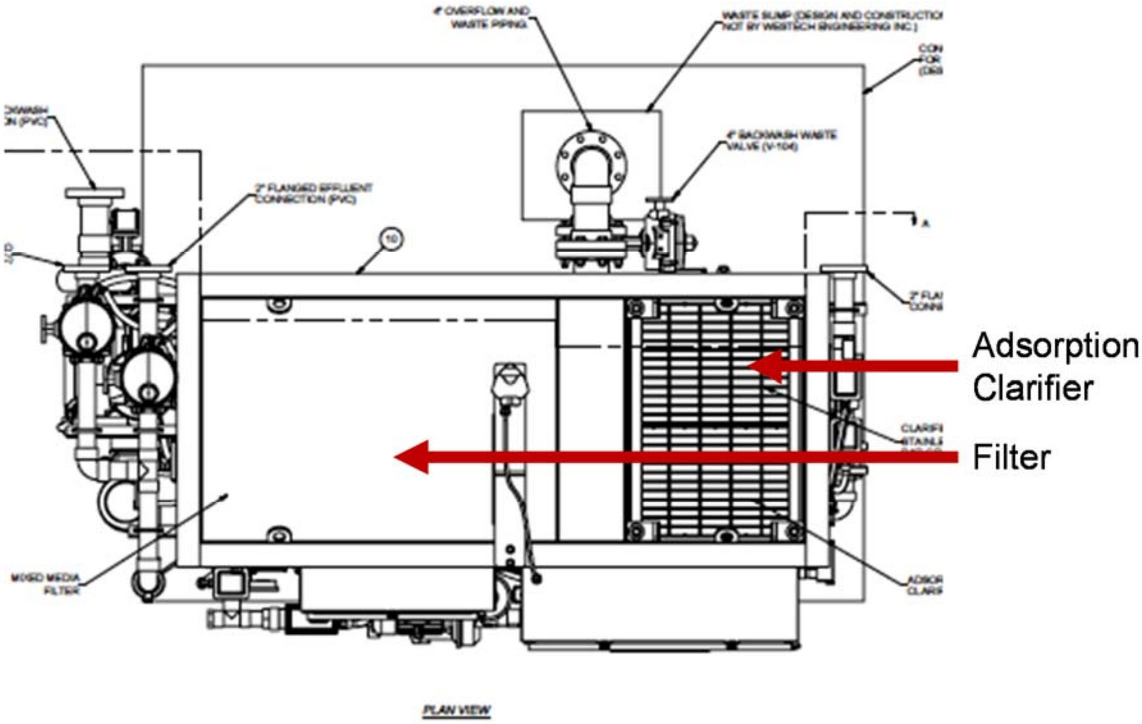


Figure 2-2 Schematic of the Microfloc® Trimite™ 50 package treatment unit

As can be seen from the schematic, there are several pieces of equipment and media within both the Adsorption Clarifier chamber and the Mixed Media Filter chamber. It is difficult to calculate the exact "effective volume" of water within each chamber. However, for the purpose of getting disinfection credits upon prechlorination through the package treatment units, an estimate of the effective volumes of the Adsorption Clarifier chamber and Mixed Media Filter chamber were developed. These calculations are shown in Table 2-2. Based on these volumes, disinfection credits were calculated as shown in Table 2-3.

Table 2-2 Estimated effective volumes of Adsorption Clarifier chamber and Mixed Media Filter chamber of the Microfloc® Trimite™ 50 package treatment plant

Adsorption Clarifier Dimensions	23 in (L) X 31.5 in (W) X 47 in (H)
Adsorption Clarifier Volume	147.4 gal
Mixed Media Filter Dimensions	46 in (L) X 31.5 in (W) X 45.5 in (H)
Mixed Media Filter Volume	285.4 gal
Total Volume: Clarifier + Filter	432.8 gal
Total Volume of 2 Trimite™ Units	865.6 gal

Clearwell Operations

The OMT WTP clearwell is typically operated at levels between 8 and 22 feet, which correspond to tank volumes of approximately 6,800 and 18,600 gallons, respectively. Figure 2-3 shows a photo of the OMT WTP clearwell. The height of the clearwell inlet riser pipe is 8 feet. There is a digital readout that indicates water level in the clearwell. Daily influent flow rates are typically less than 80 gpm, when the booster pumps are operating to direct flow from the Microfloc® units to the clearwell. The operation time of the microfloc units varies to keep pace with the distribution system demand.

Figure 2-3 OMT WTP Clearwell

Disinfection

The OTM WTP operations staff targets chlorine residual greater than 0.2 mg/L in the distribution system. Operations staff adjusts the chlorine residual leaving the WTP to achieve this distribution system target. Due to a combination of high temperatures and residual demand, the chlorine residual decreases as water moves through the distribution system.

During the testing of the aeration equipment, the point of chlorine application was moved upstream of the package treatment units, in order to achieve sufficient CT through the WTP and the clearwell. Prechlorination in the raw water was be the only point of chlorine addition during the period of testing of the aeration technologies. As indicated in Table 2-3, a chlorine residual of 3.5 mg/L was be maintained through the WTP and clearwell throughout the duration of the aeration technologies testing. The necessary disinfection of a minimum 1.0 log *Giardia* inactivation was achieved through the package treatment units and the clearwell. Table 2-3 shows a summary of the disinfection parameters for the testing period. At the conclusion of the demonstration testing, prechlorination was discontinued, and the WTP returned to normal operations of chlorinating prior to the clearwell.

Table 2-3 Summary of disinfection parameters for the testing period

Parameter	Pre-Chlorination CT Through WTP	CT Through Clearwell
Effective Basin Size (gallons)	865.6	6,800
Baffling Factor (T10/T)	0.7	0.1
Disinfection Method	Chlorine	Chlorine
Peak Flow Rate (gpm)	80	80
Disinfectant Conc. (mg/L)	3.5	3.5
pH (s.u.)	8.1	8.1
Temperature (^oC)	15.0	15.0
Contact Time T10 (minutes)	7.6	8.5
CT_{Calc}	26.51	29.75
$CT_{99.9}$ (Giardia)	162.78	162.78
Log Inactivation (G)	0.49	0.55
$CT_{99.9}$ (Viruses)	4	4
Log Inactivation (V)	26.51	29.75

The disinfection credit achieved from the clearwell and WTP combined totals 1.04 log inactivation for *Giardia*. During the testing period when aeration equipment is turned on, a log sheet including the CT parameters listed above will be completed hourly by staff onsite. Minimum cut-off values for certain parameters (clearwell level, pH, chlorine residual) in order to maintain the 1.0 log *Giardia* inactivation will be stipulated within the field log sheets. If monitoring indicates that those parameters are below the minimum stipulated values, aeration equipment will be turned off until the parameters are back within acceptable range. Based on the field recorded values, actual log inactivation achieved will be calculated daily (at the end of the day) during the period of testing. As shown in Table 2-3, CT parameters will be collected both after the WTP and after the clearwell, and log inactivation will be calculated individually through the WTP and the clearwell.

TTHM Concentrations

Under the Stage 2 DBP Rule, compliance is based on the LRAA. The IDSE report indicates TTHM LRAA concentrations in the distribution system as high as 180 ug/L for the sampling location at 24500 Windmill Road. The TTHM concentration measured near the WTP site on 4/22/2014 was 99 µg/L. Given the high TTHM concentrations OMT has observed in their distribution system, it is unlikely that aeration alone will achieve compliance. For the purpose of conducting this pilot testing, the largest aeration systems that can be fit into the existing clearwell have been identified and analysis tools have been used to estimate the TTHM reduction that can be achieved by these systems. To estimate TTHM reduction for surface aeration, the Aeration

System Analysis Program (ASAP) developed by Michigan Technological University has been used. Models developed through the Water Research Foundation Project No. 4413, Localized Control of DBPs by Spray Aeration in Storage Tanks, have been used for spray aeration performance estimates. The results from modeling TTHM reduction is summarized in Table 2-4.

Table 2-4 TTHM reduction modeling results

Parameter	Model Results		Comment
	Surface Aeration	Spray Aeration	
TTHM at Clearwell (ug/L)	100		Sample date 4/22/2014
TTHM leaving clearwell (µg/L)	40	50	Estimated by models for 2 hp surface aerator and 3 hp pump for spray aeration
TTHM Reduction at Clearwell	60%	50%	

AERATION EVALUATION AND DESIGN

Since TTHMs are volatile, they can be removed with enhancing air / water contact through aeration. Aeration can remove TTHMs from water by enhancing a contact surface between air and water. The removal efficiency depends upon the volatility of the individual TTHM species related to the Henry's Constant, which increases with temperature. Higher Henry's constant results in higher species volatility.

Two aeration strategies were evaluated to reduce TTHMs in the OMT WTP clearwell, including spray aeration and surface aeration. The following subsections provide an overview of the spray aeration and surface aeration treatment technologies. It should be noted that aeration does not effectively remove HAA5s from water since they are much less volatile than TTHMs.

Spray Aeration

The spray aeration system included an NSF 61 certified submersible pump, discharge pipe to direct flow to the reservoir ceiling, and spiral spray nozzle. A Dayton 3 hp pump/ motor (230V, 14 amps) with control box was used for the spray aeration system. A photo of the pump/ motor is shown in Figure 2-4. Water in the reservoir passed through the spray nozzle to form small droplets with high surface area that were sprayed into the reservoir. Two 1-1/2 inch full cone BETE Fog nozzles (Model TF64FCN) were used in the spray aeration system design, as shown in Figure 2-5. The design parameters that influence TTHM removal efficiency include the water droplet size and air-water contact time. For spray aeration the model for TTHM reduction was developed through the Water Research Foundation Project No. 4413, Localized Control of DBPs by Spray Aeration in Storage Tanks. The design assumptions used in the modeling are summarized in Table 2-5.

Table 2-5 Spray aeration modeling assumptions

Parameter	Value	Comment
Reservoir volume (gallons)	6,800	Minimum operating volume for test period
Minimum distance to water (ft)	2	Based on spray nozzle attached at a tank elevation of 24 feet
Influent flow rate (gpm)	80	Maximum operating flow for test period
Spray flow rate (gpm)	84	

For the spray aeration pumping flow rate of 84 gpm, it was estimated that 50% TTHM reduction will be achieved at the clearwell.

Figure 2-4 Photo of the spray aeration pump used for demonstration testing

Figure 2-5 Photo of the spray aeration nozzles used for demonstration testing

Surface Aeration

With this alternative, a floating surface aerator was installed in the clearwell. The aerator constantly drew in water from beneath the water surface, and sprayed it laterally through the air. For surface aeration installations in Phoenix, Arizona, the mixing has been investigated though monitoring and computational fluid dynamics modeling (Seidel et al. 2010). These analyses suggest that near complete mixing is achieved with the use of a surface aerator. This mixing is accomplished by the aerator drawing water from below the surface and discharging it radially over the water surface. A 2 hp aerator draws water and discharges it at a rate of approximately 690 gpm with an impingement (white water) diameter of 7 feet.

TTHM reduction with surface aeration is proportional to the energy applied to the water in the reservoir. As indicated above, the model developed by Michigan Technological University, Aeration System Analysis Program (ASAP™, Michigan Technological University 1999), was utilized to determine the TTHM removal that could be expected. The conditions that were evaluated using the ASAP™ model are shown in Table 2-6.

Table 2-6 Surface aeration modeling assumptions

Parameter	Value	Comment
Reservoir volume (gallons)	6,800	Minimum operating volume for test period
Influent flow rate (gpm)	80	Maximum operating flow for test period
Power applied (hp)	2	

The model results suggested that a power input of 2 hp applied in the clearwell would achieve approximately 60% TTHM reduction.

The surface aerator selected for this application was designed with a collapsible float. A photo of this collapsible float is shown in Figure 2-6. This float design allows for the aerator to be installed and maintained through the existing 24 inch square hatch. The surface aeration unit was secured with posts to allow the unit to float in place as water levels changed in the reservoir.

Figure 2-6 Photo of the surface aeration float used for demonstration testing

Tank Mixer

A tank mixer was used during one phase of the demonstration testing – tank mixer and active ventilation. The objective of using the mixer was to ensure that the water in the tank is not stratified, and there is uniform water quality throughout the depth of the tank. A 120V tank mixer (PAX Water PWM 100) was used for tank mixing, as shown in Figure 2-7.

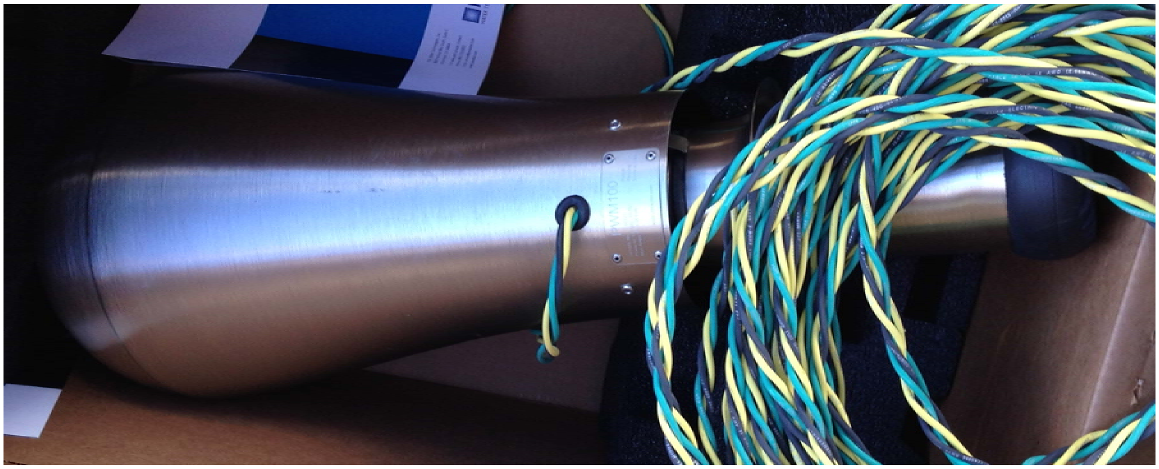


Figure 2-7 Photo of the tank mixer used for demonstration testing

Ventilation

Existing full scale aeration installations for TTHM reduction have demonstrated that best performance can be achieved with exhausting of air in the reservoir headspace and replacing it with outside, fresh air. This reservoir head space air exchange was achieved through the use of a 120 volt air supply fan. The air flow rate is a function of the pressure loss that may happen over time, but even with a pressure loss of 0.75 inches water column (W.C.), the air flow rate was about 130 cfm (refer to fan cut sheet provided in Appendix A). Based on the project team's calculations, the minimum ventilation required for renewal of air in the tank head space is 100 cfm, so the selected fan provided greater air flow than that. The ventilation fan was used during the following phases of testing:

- Active ventilation
- Tank mixer and active ventilation
- Surface aerator with active ventilation
- Spray aeration system with active ventilation

The fan intake air was filtered through #35, Type 316L stainless steel screen to prevent contaminant entry. A Camfil Multi Track 25 Filter Housing and Camfil 30/30 Minimum Efficiency Reporting Value (MERV) 8 2-inch filter was used to filter the inlet air. The ventilation fan and filter assembly were placed outside the clearwell, a few inches above the ground such that they were away from dusts and in contact with free flowing air. The filtered air was in compliance with ODEQ construction standard, OAC 252:626-9-3.b(5) which states that forced or induced draft aeration devices should be designed to ensure air introduced in the column is free from obnoxious fumes, dust, and dirt, as possible. The existing screened mushroom vent was used for the air exhaust.

TTHM Monitoring Equipment

As described later in Chapter 3, a detailed sampling and analyses plan was developed as part of the demonstration testing for monitoring of all water quality parameters. TTHM samples were part of the sampling and analyses along with other parameters. However, given the objectives of this project, two additional TTHM monitoring was analyzers were procured for analyses of TTHMs in the WTP effluent and the clearwell effluent. As described below, one of the TTHM analyzers was a continuous online analyzer, while the other one was used for grab sample analyses.

Aqua Metrology Systems THM 100™ Online TTHM Analyzer

The automated, online THM 100™ analyzer uses a "purge and trap" sampling method followed by desorption into a chemical mixture that generates a colored product and time-resolved spectrophotometric analysis for detection and determination of THM levels. THM levels were monitored every 4 hours through the self-calibrating instrument. Monitored results are available through communication options including 4-20 mA, wireless or USB. A photo of the THM 100™ analyzer is shown in Figure 2-8.

Figure 2-8 Photo of the AMS THM 100™ analyzer used for demonstration testing

Parker THM Analyzer

The Parker THM analyzer is an easy to operate, “purge and trap” gas chromatograph (GC) that can measure THM concentrations in less than 30 minutes without tedious sample preparation. The instrument comes with a laptop computer pre-loaded with THM analyzer software. A helium gas supply is necessary for the operation of the instrument. Upon completion of analyses, THM results are displayed on the analyzer touchscreen and laptop display, and are automatically archived for future access and review. A photo of the Parker THM analyzer and the laptop with the requisite analyzer software is shown in Figure 2-9.

Figure 2-9 Photo of the Parker THM analyzer used for demonstration

EQUIPMENT SPECIFICATIONS

Drawings for the aeration equipment installation were included in the Engineering Design Report submitted to the Oklahoma Department of Environmental Quality (ODEQ). The report is attached in its entirety in Appendix A including cut sheets for selected equipment. Installation of aeration equipment includes the following elements:

- A 2 hp, NSF 61 certified surface aerator. The surface aerator was disinfected with a low concentration solution prior to installation in the clearwell (approx. 0.02% sodium hypochlorite in accordance with AWWA C652-11 Disinfection of Water Storage Facilities Section 4.4.6 Equipment and Personnel).
- A 3 hp, NSF 61 certified submersible pump. The submersible pump was disinfected with a low concentration solution prior to installation in the clearwell (approx. 0.02% sodium hypochlorite in accordance with AWWA C652-11 Disinfection of Water Storage Facilities Section 4.4.6 Equipment and Personnel).
- Installation of two bolted pipes to secure the aeration unit. One of the pipes conveyed spray aeration flow to the top of the reservoir.
- Two PVC nozzles for the spray aeration system.
- A 120 VAC tank mixer.
- Installation of 120 VAC air supply fan. At a pressure drop across the fan and screen of 0.75 in W.C., the selected fan air flow rate is approximately 130 scfm, which was

sufficient to facilitate TTHM reduction. To confirm this design target is met, air flow was measured using a hand held anemometer.

- Two penetrations for aeration power supply.

PROCESS CONTROL

The following process controls were required for aeration equipment:

- Panel with run status lights to indicate whether the aerator and pump are operating and ability to start/stop aerator and pump. The start and stop times of the surface aerator and spray aeration pump were recorded daily as part of the data logging process.
- Two watt meters were added between the panel and the starters of the surface aerator and the spray aeration pump. The watt meters recorded the actual power consumption of each technology over time.
- Switch with the ability to start/ stop the ventilation fan. Fan speed variation not planned as part of testing. The start and stop times of the ventilation fan were recorded daily as part of the data logging process.
- Two floor plates with EPDM pads were placed below the aerator and submersible pump to prevent contact with the reservoir floor if drained for maintenance.

AIR QUALITY EMISSIONS

Given the maximum influent flow of 80 gpm and assuming a conservative maximum TTHM concentration at the clearwell of 180 µg/L, approximately 0.175 lb/day of VOC was estimated to be released if all TTHMs were removed and if the WTP operated continuously for the entire day at those conditions. This is well below the regulatory limit of 2 lb/day.

PROJECT SCHEDULE

The utility selection, the design and permitting process of the aeration equipment, and coordination with equipment installers took longer than anticipated, so the demonstration testing could not be performed according to the original project schedule. Table 2-7 lists the key dates of the project schedule, and shows that the demonstration testing was conducted between November 2014 and January 2015. Note that at the onset of the project it was anticipated that the demonstration testing would be performed during the summer months, but because of the delays and contracting constraints, the project has to be completed according to the schedule shown in Table 2-7.

Table 2-7 Project schedule

Task	Date
Utility Selection Completed	4/30/2014
Initial Design Submittal	6/29/2014
Final Design Submittal	8/15/2014
ODEQ Construction Permit Approval	10/22/2014
Equipment Installation	11/10/2014
Begin Test Program	11/12/2014
Completion of Testing	1/25/2015

The testing period included the following test phases:

- Baseline conditions (normal operation)
- Active ventilation
- Tank mixer and active ventilation
- Surface aerator with active ventilation
- Surface aerator with passive ventilation
- Spray aeration system with active ventilation
- Spray aeration system with passive ventilation.

Each test phase was continued for a one week period. The baseline condition was repeated at the beginning and at the end of the test period. Some test conditions were repeated in order to collect confirmatory data.

CHAPTER 3
EQUIPMENT INSTALLATION AND DEMONSTRATION TEST PROTOCOL

Given that this was a full-scale installation, albeit temporary, an application for permit to construct was filed with ODEQ in August 2014, along with the finalized Engineering Design Report (EDR). The EDR and the pilot study protocol were approved by ODEQ in October 2014. Once approved, the aeration equipment was installed in the OTOE WTP clearwell in November 2014, and demonstration tests conducted between November 2014 and January 2015.

The aeration equipment installation was performed in accordance with the guidelines prescribed in AWWA Standard C652-11 "Disinfection of Water Storage Facilities". A water quality sampling plan was implemented at the OMT WTP and in the distribution system to evaluate the reduction of TTHM concentrations with aeration equipment, as well as the impact on other drinking water quality parameters including chlorine residual. The following sections summarize the equipment installation, test operations, sampling and monitoring program.

EQUIPMENT INSTALLATION

The aeration equipment was installed (and uninstalled) "live" while the WTP and the clearwell were still online. The aeration equipment installation inside the clearwell was performed by Midco Diving and Marine Services. Installation of equipment outside the clearwell, as well as all electrical connections were performed by Haynes Equipment. The live installation was performed by divers who were in constant communication with field engineers via a video feed. The entire equipment installation process was recorded and archived for future reference. A photo of the Midco van with the video screen, recording and communication devices are shown in Figure 3-1.

All equipment and materials installed within the reservoir for aeration testing were NSF 61 certified. All the aeration equipment were installed at one time, and uninstalled at one time as well. There were some troubleshooting necessary following the aeration equipment installation, however, entry inside the clearwell was not necessary during the troubleshooting processes. The issues were related to the alignment of electrical cables of the mixer, the spray aeration pump, and the surface aerator.

Prior to the installation of the aeration equipment, the clearwell floor was cleaned of all flocculated material, silt, sediment, sand, and any other accumulated debris. This was done by the equipment installer utilizing the proprietary HydroDyne Cleaning System. The clearwell had not been cleaned for several years prior to this installation, and as such, significant debris had accumulated on the clearwell floor. The solids were pumped out and discharged into the WTPs backwash water lagoons, as shown in Figure 3-2.

Figure 3-1 Video communication between Midco divers and field

Figure 3-2 Discharge of clearwell solids into WTP backwash water lagoon

The following sections describe details of the operational plan of the WTP and the clearwell during the installation and uninstallation process, the associated sampling plan, and a contingency plan that was in place in the event of a positive total coliform sample result.

Standard Operational Procedure during Aeration Equipment Installation/ Uninstallation

The aeration equipment installation and uninstallation were performed in accordance with AWWA Standard C652-11, Section 4.4. Specific items considered during the installation/ uninstallation process are mentioned below, these items were adapted directly from AWWA Standard C652-11, Section 4.4:

- A pre-job meeting (via conference call) was held on November 4, 2014, that included the WRF 4441 project team members, OTOE- Missouria WTP personnel, and the equipment installation contractor. During this meeting the equipment installation and uninstallation processes were reviewed including disinfection procedures, time restrictions, diving conditions, and safety procedures.
- During the equipment installation and uninstallation in the clearwell, a positive flow into the clearwell was maintained, and flow rates into and out of the clearwell were minimal.
- Equipment and personnel entering the clearwell were cleaned and disinfected immediately prior to entry into the clearwell. The access hatch at the top of the clearwell and the immediate area surrounding the access hatch were cleaned prior to equipment installation and uninstallation. The method of equipment disinfection was spraying with the disinfectant solution. The diver and the clothing were disinfected after the diver was suited up and on top of the clearwell.
- Water quality sampling and analyses was performed prior to, during, and upon completion of installation of the aeration equipment in the clearwell. A detailed description of the water quality sampling and analyses performed is described in the following sub-section.
- All equipment used during the installation/ uninstallation process were maintained in such a fashion that water quality was not affected. Divers were completely encapsulated with no bare skin exposed. Diving clothing were of the dry-suit type and in good condition, free from tears, scrapes, unrepaired areas, or other imperfection that impair the integrity of the suit. There was no contact of the mouth or head with the water. The head was fully encapsulated by one or a combination of helmet or dry suit hood with full-face mask. Figure 3-3 shows a photo of a diver in suit and helmet prior to entry into the clearwell.

Figure 3-3 Diver in suit and helmet prior to entry inside the clearwell

- Divers had communication in accordance with federal, state, and local regulations.
- This work, which combined elevated work, confined space entry, and diving, was hazardous in nature and the contractor performing the work complied with all federal, state, and local regulations. All diving operations were conducted by certified divers who had graduated from an ACDE Approved Commercial Diving Course. Personnel on the dive team were also OSHA Confined Space Certified. All personnel on the dive team were free of communicable disease and were not under a physician's care within the seven-day period prior to entering of the clearwell. The dive team members were certified by the American Red Cross or an equivalent in the use of CPR and First Aid.
- The dive team complied with all applicable local, state, and federal safety requirements. The equipment installation contractor had a comprehensive safety manual on-site, which addressed all of the potential hazards. The safety manual included certifications of all safety and emergency response requirements at the site. The contractor had a method and the equipment readily available for the extraction of an injured diver and a method for lowering a person to the ground in case someone were to be incapacitated.
- Heavy equipment such as steel pipes, surface aerator and float that needed to be installed within the clearwell were raised using a boom truck with a 2 stage jib and a hook. Figure 3-4 shows a photo of the boom truck setup during equipment installation. Figure 3-5 shows the surface aeration float being lowered into the clearwell while being supported by the boom.

Figure 3-4 Boom truck set up during aeration equipment installation

Figure 3-5 Surface aerator float being lowered into the clearwell using boom truck

Water Quality Sampling During Aeration Equipment Installation/ Uninstallation

Water quality sampling was performed prior to, during, and after the aeration equipment installation and uninstallation processes in order to ensure that the treated water quality met all applicable water quality standards and was safe to be pumped to the distribution system. The water quality sampling procedure is described briefly below, and was directly adapted from AWWA Standard C652-11, Section 5:

- An initial water quality analysis of the clearwell water was performed prior to equipment installation/ uninstallation. Measured water quality parameters included chlorine residual, turbidity, pH, and alkalinity. The methods used for analyses of water quality parameters were in accordance with the latest edition of *Standard Methods for the Examination of Water and Wastewater*. The water quality parameters were sampled and recorded every day during the installation/ uninstallation process prior to the commencement of work inside the clearwell.
- Additionally, on the days that work was conducted related to the installation/ uninstallation process, total coliform and chlorine residual samples were also collected and analyzed from the clearwell effluent. As suggested by ODEQ, all total coliform samples collected during this project (during equipment installation and demonstration testing) were labeled as "non-compliance" samples in the sample chain of custodies.
- If the total coliform test were to show the presence of coliform bacteria, the WTP and the clearwell would have been taken offline and disinfected. Repeat samples would have been collected until two consecutive samples were negative. The WTP and the clearwell would have been placed in service only after two consecutive repeat samples showed negative total coliform bacteria.
- Clearwell effluent samples were collected from a sample tap on the outlet piping of the clearwell. This sampling point was installed on the pipe leading to the high service pumps prior to commencement of the testing.
- For every total coliform sample collected from the outlet piping of the clearwell, an additional chlorine residual and total coliform sample were also collected from water flowing into the clearwell. This was done to determine if coliforms were present in the feed water to the clearwell.

Contingency Planning for Meeting Water Demand during Aeration Equipment Installation/ Uninstallation

It has been noted previously that the OTOE- Missouria WTP is the sole source for the production of drinking water for the community. Additionally, there are no emergency interconnects with any other neighboring community. As such, contingency planning was key to ensure that water supply to the community was not disrupted during the aeration equipment installation and uninstallation processes. The following measures were planned to be adopted during the equipment installation/ uninstallation processes as part of contingency planning:

- Outside of the WTP, the tribe has a 120,000 gallon distribution system standpipe that will serve as the primary storage of water during the aeration equipment installation/ uninstallation period. Prior to the commencement of any installation/ uninstallation activities, water will be pumped into this standpipe and it will be filled to the maximum capacity allowable by hydraulic constraints.

- Prior to commencement of any installation/ uninstallation period, it will be ensured that the chlorine residual in the treated water being pumped to the distribution system standpipe is high, approximately 3.5 mg/L. This ensures that even after a comparatively long hydraulic residence time within the standpipe, the water in the distribution system is not depleted of chlorine residual.
- On the days of equipment installation/ uninstallation, activities will be initiated as early in the day as possible. This allows for collection of total coliform samples and shipping them to the Laboratory on the same day that equipment installation/ uninstallation is performed.
- While the installation/ uninstallation processes will be performed "live" with the WTP and clearwell in service, water flow rates into and out of the clearwell will be kept to a minimum. Full production at the WTP and pumping with high service pumps will only resume once the equipment installation/ uninstallation processes are complete.
- In case the total coliform sample result from the Laboratory is "positive" indicating presence of coliform bacteria, the following response actions will be executed:

    - The WTP and the clearwell will be immediately taken offline and isolated from the distribution system
    - All WTP processes and clearwell will be disinfected using a high dose of chlorine
    - Post disinfection, the water with the high chlorine residual will be drained, collected and safely disposed of
    - A chlorine residual and total coliform sample will be collected from the clearwell effluent post disinfection
    - An additional chlorine residual and total coliform sample will be collected from a representative location in the distribution system
    - The WTP and the clearwell will not be put back in service until two consecutive total coliform samples from the clearwell effluent are "negative"
    - The distribution system standpipe will be used for the supply of potable water until the WTP and clearwell can be put back in service
    - Depending on the results of the initial total coliform sample, and any repeat samples, the tribe will issue boil water advisories or boil water notices to their community in accordance with applicable federal, state, and local regulations
    - The tribe will also send out communications to their community describing the situation and urging conservation practices until the water supply can be restored at the WTP
    - Once the WTP and the clearwell has been put back in service, another chlorine residual and total coliform sample will be collected from a representative location in the distribution system.

BASELINE SAMPLING

Sampling was conducted prior to the start of the aeration testing to identify baseline water quality conditions. This baseline water quality sampling was conducted with the plant operating with pre-chlorination in the raw water as described in Chapter 2. The sampling followed the same format as for the aeration testing period described in the next subsection. Baseline data was obtained for approximately two weeks at the beginning of the two month testing period. It should be noted that the clearwell influent (i.e. WTP effluent) samples were collected when the WTP was operating to assure the sample is representative of water entering the tank. The clearwell effluent samples were collected when the booster pumps are running to assure the sample was representative of water leaving the tank.

AERATION TESTING PERIOD SAMPLING

During the aeration testing period, the following water quality parameters were monitored at each sampling location as listed in Table 3-1. Samples were collected during each phase of testing throughout the demonstration testing period. The sampling plan included monitoring for clearwell CT as discussed in Chapter 2 of this report. As discussed in Chapter 2, log inactivation of *Giardia* was calculated for each set of field recorded values. Log inactivation of *Giardia* was calculated separately for the WTP and the clearwell, as discussed later in Chapter 4.

Laboratory analyses for this project were conducted by Accurate Labs Inc. in Stillwater, OK, and American Water Central Laboratory in Belleville, IL. Accurate Labs Inc. is an ODEQ certified laboratory (Laboratory Certificate # 2014-084). American Water Central Laboratory is not an ODEQ certified laboratory, but has TNI (The NELAC Institute) accreditation – a program recognized in Oklahoma.

Table 3-1 Parameters monitored during aeration testing

Location	Parameter	Frequency
Raw Water (prior to chlorination)	TOC & Bromide	Weekly
Clearwell Inlet (WTP Effluent)	TTHM	Daily samples during each testing phase
	HAA5	One sample during weeks of testing for baseline and aeration conditions surface and spray with ventilation
	TOC	Weekly when WTP online
	Free Cl_2 (field)	Daily when WTP online and aeration testing ongoing
	pH (field)	Daily when WTP online and aeration testing ongoing
	Temperature (field)	Daily when WTP online and aeration testing ongoing
	Flow Rate (field)	Hourly every day when WTP online and aeration testing ongoing
Clearwell Effluent	TTHM	Daily during each testing phase when booster pumps are on, collect additional sample prior to turning aeration equipment on (monitoring with AMS THM-100 online analyzer every 4 hours)
	HAA5	One sample during weeks of testing for baseline and aeration conditions surface and spray with ventilation
	Free Cl_2 (field)	Daily when WTP and booster pumps are online and aeration testing ongoing (existing WTP analyzer used for comparison)
	pH (field)	Daily when WTP and booster pumps are online and aeration testing ongoing
	Temperature (field)	Daily when WTP and booster pumps are online and aeration testing ongoing
	Flow Rate (field)	Hourly every day when WTP and booster pumps are online and aeration testing ongoing
	Level (field)	Hourly every day when WTP and booster pumps are online and aeration testing ongoing

CHLORINE RESIDUAL MANAGEMENT

Chlorine residual is continuously monitored at the WTP injection point to the distribution system. The amount of chlorine residual reduction caused by aeration equipment was minimal. Chlorine residual was monitored at the WTP effluent and clearwell effluent at the frequency specified in Table 3-1 to determine the appropriate chlorine doses.

CHAPTER 4
DEMONSTRATION TEST RESULTS

As described in Chapter 3, the approval for permit to construct was received from ODEQ in October 2014, the equipment installation was performed in November 2014, and the demonstration tests were carried out between November 2014 and January 2015. During the demonstration testing, a significant amount of data was collected related to OMT WTP operations, water quality, and TTHM removal. Specifically, the data collected included the following:

- WTP Operational Data
    - WTP on and off times and run duration
    - Flow rate
    - Chemical doses
- High Service Pumps Operational Data
    - On and off times and run duration
    - Flow rate
- Water Quality Data
    - Raw water
        - pH, alkalinity, TOC, UV-254, bromide
    - WTP treated water
        - pH, alkalinity, TOC, UV-254, chlorine residual, TTHM, HAA5, TOX (total organic halides)
    - Clearwell effluent water
        - pH, alkalinity, chlorine residual, TTHM, HAA5, TOX

Given the focus of this project on TTHMs, TTHM data was collected using multiple field analytical instruments and laboratory samples from the various sampling locations at the WTP. The AMS THM100™ instrument was placed online with the clearwell effluent sample, and it automatically recorded TTHM data every 4 hours throughout the two months of demonstration testing. The Parker THM analyzer was used to measure TTHM concentrations of grab samples collected from the WTP effluent and clearwell effluent on a daily basis throughout the two month demonstration testing. Duplicate samples were also collected from both the WTP effluent and clearwell effluent on a daily basis and sent for laboratory analyses.

WTP OPERATIONS

As described earlier, once the aeration equipment installation was completed, the OMT WTP was operated normally to meet system demand without any modifications due to the aeration equipment operation. The only exception to normal operations at this time was the relocation of the chlorine feed point to upstream of the WTP. Different phases of the aeration demonstration testing was carried out over two months, while the WTP and the high service pumps were operating normally. It is important to understand the WTP and high service pump operations, as they have a significant influence on clearwell water levels, hydraulic residence time in the clearwell, and consequently aeration technology effectiveness.

During the months of November through January, there is lower water demand in the OMT distribution system compared to summer months. As such, the operators run the WTP during the daytime hours, typically between 7 AM and 6 PM. With the exception of a few days, the WTP was not operated between 6 PM and 7 AM the following day. Similarly, the high service pumps were also operated during daytime hours only, and with the exception of a few days, not operated between 6 PM and 7 AM the following day. Also, the high service pumps were operated 2 to 4 times every day. Each time, the pumps were switched on for between 20 minutes and 2 hours (typically between 1 hour and 1.5 hours). The duration of operation of the high service pumps were dictated by the water level in the distribution system water tower. The tribe operates their water tower between water levels of 90 feet and 110 feet.

Table 4-1 shows the WTP operational details between November 2014 and January 2015. As seen in the table, the average total WTP production between November and January is approximately half of the WTP's peak production during summer months (70,000 – 80,000 gpd).

Table 4-1 OMT WTP operational details between November 2014 and January 2015

Parameter	WTP	High Service Pumps
Flow rate (gpm)	72-86 (both Trimite units operating)	156 (both high service pumps operating)
Hours of operation/ day	8 – 10	3.5 - 5
Total production (gpd)	34,000 – 47,000	32,000 – 46,000

Figure 4-1 shows the WTP production on December 1 and 2, 2014. Also shown in the figure are the start and stop times of the high service pumps. As seen in the figure, both the WTP and the high service pumps operated between 7 AM and 5 PM on December 1, and were shut down after 5 PM until 7 AM on December 2. This operational trend was consistent throughout the two months of the demonstration testing period.

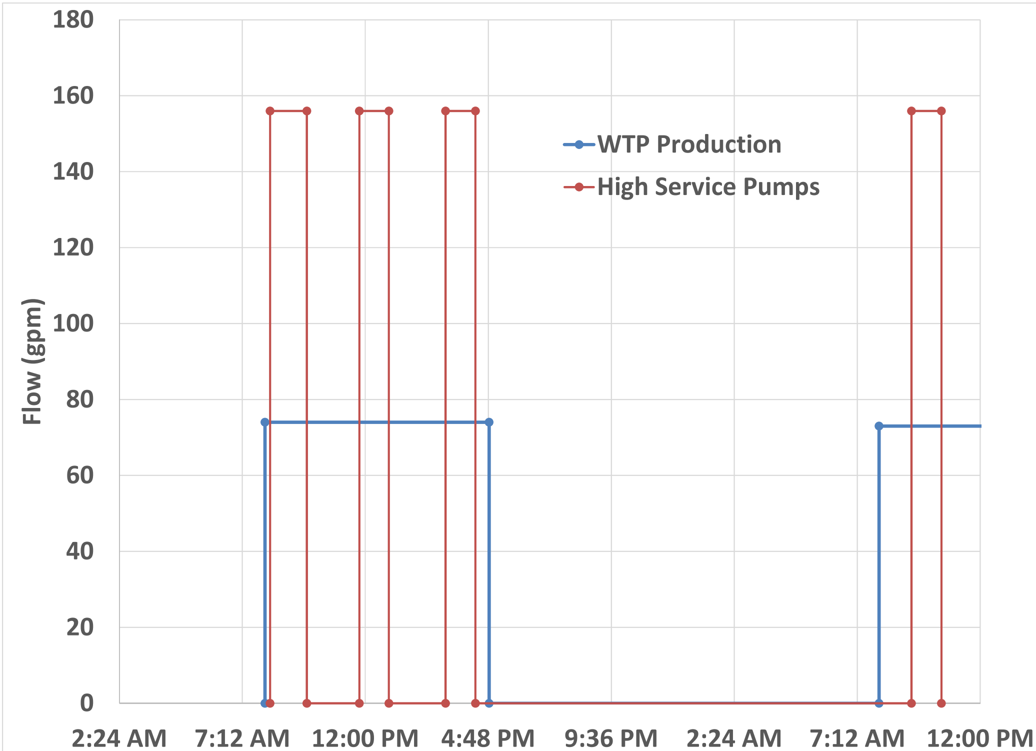


Figure 4-1 OMT WTP and high service pumps operation on December 1 and 2, 2014

As seen in Figure 4-1, the OMT WTP was operated continuously between 7 AM and 5 PM on December 1, 2014. On this particular day, the production was not interrupted due to backwashing of the Trimite units. Typically, each of the two Trimite units are backwashed once every 48 to 72 hours. The backwash is triggered by filtrate turbidity. When one of the units is backwashed, it typically is offline for approximately 30 minutes, prior to returning back to service. During this period, the WTP production is either reduced by 50 percent, or completely stopped until the backwash event(s) are completed.

As evident from Figure 4-2, during daytime hours when either the WTP is producing water, or when the high service pumps are operating, or both are happening simultaneously, the water level and water volume in the clearwell are continuously changing. Figure 4-2 shows the change in the water volume in the clearwell for the same two days (December 1 and 2, 2014). However, as seen in Figure 4-2, the water volume in the clearwell stays constant during evening and night hours until the next morning.

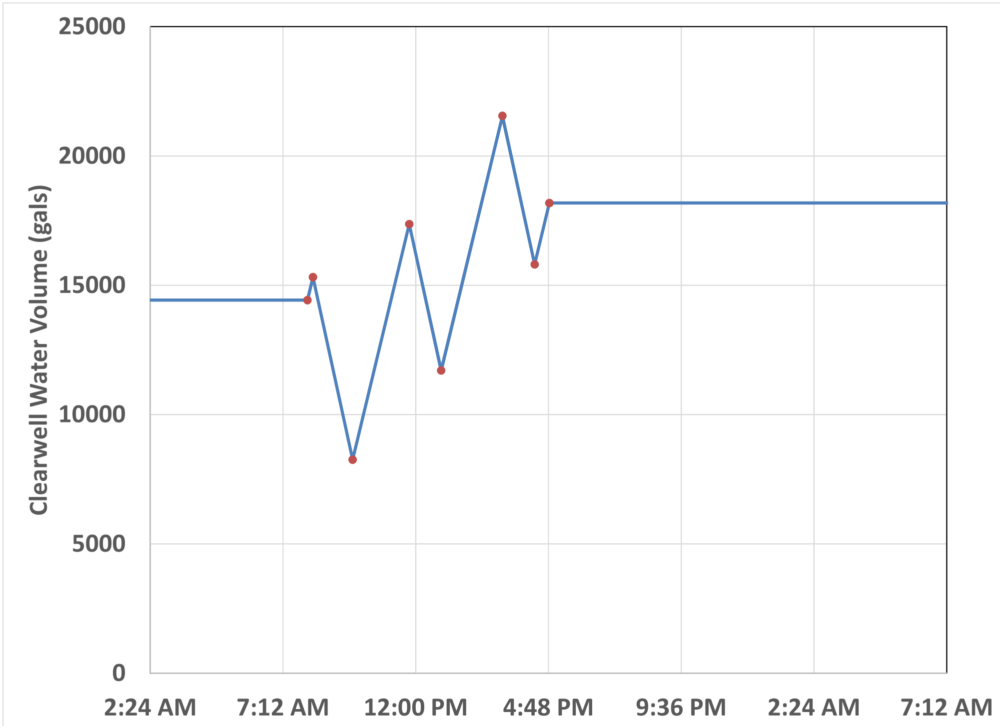


Figure 4-2 OMT WTP clearwell water volume on December 1, 2014

This variation in clearwell level and volume has a significant effect on the effectiveness of aeration technologies. That is because the effectiveness of aeration technologies in TTHM reduction is directly proportional to the hydraulic residence time of the water in the clearwell. During the daytime hours when either or both of the WTP and high service pumps are in operation, the average hydraulic residence time of water in the reservoir can be as low as 2 hours. At such low hydraulic residence times, there is not sufficient formation of TTHM within the clearwell that can be removed. As such, the performance of any aeration system in TTHM removal is likely to be less than optimal under these conditions.

WATER QUALITY

Table 4-2 presents the water quality in the OMT WTP raw and treated water between November 2014 and January 2015. During this two month demonstration testing period, there was no significant change in raw water quality. As can be seen in the table, the water temperature experienced during the demonstration testing was lower than the minimum water temperature of 15°C anticipated during the development of the EDR. Also, the table illustrates that the WTP treatment processes do not remove a significant fraction of the raw water TOC, except the fraction associated with particulates. The UV-254 in the WTP treated water was 0.084 cm^{-1}, but the clearwell effluent water had a UV-254 value of 0.059 cm^{-1}.

Table 4-2 OMT WTP raw and treated water quality between November 2014 and January 2015

Water Quality Parameter	Raw Water	WTP Effluent
Temperature (C)	12.2 – 14.4	
pH	7.9 – 8.0	8.4 – 8.5
Alkalinity (mg/L as $CaCO_3$)	207	148
Total Organic Carbon (TOC, mg/L)	3.5 – 3.7	3.0 – 3.1
UV-254 (1/cm)	0.267	0.084
Bromide (mg/L)	0.41	

Chlorine residual was monitored daily in the WTP effluent and the clearwell effluent. Additionally, the clearwell effluent has an online chlorine analyzer (CL-17), and readings from the analyzer were recorded every 4 hours during the demonstration testing period. Chlorine residual data are not shown here, but the chlorine residual in the WTP effluent varied between 6.5 and 8.2 mg/L. Chlorine residual in the clearwell effluent varied between 2.5 and 3.8 mg/L.

Throughout the duration of the demonstration testing, every effort was made to ensure that sufficient disinfection exceeding 1-log *Giardia* inactivation was provided through the WTP and the clearwell. Conditions experienced during the two month demonstration testing were different than what were anticipated at the time of development of the EDR. Table 4-3 summarizes the worst-case disinfection conditions that were experienced during the two month demonstration testing. When this table is compared to Table 2-3 in Chapter 2, the differences that were observed are shown in bold text in Table 4-3.

It needs to be reemphasized that the conditions listed in Table 4-3 are the worst-case scenario that occurred during the daytime hours when both the WTP and the high service pumps were in operation. At all other times, the hydraulic residence time is greater than the value shown in the table, and as such, a higher CT value is achieved. For example, during overnight hours when there is no water inflow or outflow from the clearwell, a significantly higher CT is achieved. Secondly, the effective basin size for the clearwell shown in Table 4-3 is based on a water level of 12 feet. While this was stipulated to be the minimum water level, the actual water level variation in the clearwell during the two month demonstration testing was between 14 and 20 feet. Consequently, with the higher volume of water in the clearwell, a higher CT was achieved than described in Table 4-3.

Table 4-3 Summary of disinfection parameters experienced during the two month demonstration testing

Parameter	Pre-Chlorination CT Through WTP	CT Through Clearwell
Effective Basin Size (gallons)	865.6	**10,146**
Baffling Factor (T10/T)	0.7	0.1
Disinfection Method	Chlorine	Chlorine
Peak Flow Rate (gpm)	80	80
Disinfectant Conc. (mg/L)	**6.5**	**2.5**
pH (s.u.)	**8.0**	**8.5**
Temperature (°C)	**12.2**	**12.2**
Contact Time T10 (minutes)	7.6	**12.68**
CT_{Calc}	**49.23**	**31.71**
$CT_{99.9}$ (Giardia)	**270.27**	**202.47**
Log Inactivation (G)	**0.55**	**0.47**
$CT_{99.9}$ (Viruses)	**5.2**	**5.2**
Log Inactivation (V)	**37.87**	**24.39**

TTHM RESULTS

The effectiveness of aeration technologies in the removal of TTHMs was the primary focus of this project. However, the positioning of the aeration equipment inside the clearwell, instead of a distribution system reservoir had some significant consequences. This is due to the fact that in this particular scenario, the majority of the TTHM formation occurs within the clearwell. So the TTHM removal by aeration equipment is offset by additional TTHM formation. A brief discussion of the kinetics of TTHM formation is necessary to illustrate the various processes that simultaneously occurred inside the clearwell during the two month demonstration testing period.

Figure 4-3 shows the TTHM and HAA5 formation as a function of time in a hypothetical water sample as predicted by the EPA Water Treatment Plant (WTP) Model (EPA 1994). The water quality and chlorine dose used for the model run are also shown in the figure. While the water quality parameters for the hypothetical water sample shown in Figure 4-3 is different than the OMT WTP water quality, it is evident from the figure that TTHM formation continues for a period of time exceeding 72 hours, after the point of chlorine addition. The slope of the TTHM formation curve is steepest during the first 3 hours, after which it gradually flattens out. It is to be noted here that if the residence time in the clearwell is significant compared to the remainder of the distribution system, then a clearwell aeration approach may yield successful results in TTHM reduction.

In comparison, the hydraulic residence time of water in the WTP after chlorine addition, and prior to entry into the clearwell is approximately 20 minutes. It is evident from Figure 4-3 that the reaction between chlorine and organics in the water is incomplete within that time, and as such only a fraction of the TTHMs that are ultimately formed, are formed within the first 20 minutes. As such, the TTHM formation reaction continues within the clearwell, as more TTHMs are formed. The observed TTHMs in the clearwell effluent are a combination of two processes:

- Formation of TTHMs due to reaction between chlorine and organics
- Removal of TTHMs via aeration technologies

In a typical distribution system reservoir, the TTHM formation reaction would be complete (or close to complete), and as such, TTHM removal via aeration technologies can be quantified as:

TTHM removal = TTHM at reservoir inlet – TTHM at reservoir outlet

However, this equation cannot be used in this case, because of the TTHM formation reaction, and the fact that in the OMT WTP clearwell, TTHMs at the reservoir outlet were always occurring at a higher concentration than TTHMs at the reservoir inlet. For the OMT WTP testing, a baseline condition needed to be tested – which was determination of TTHM formation when no aeration system was operational. Thereafter, comparison of TTHMs in the clearwell effluent between baseline conditions and aeration conditions would indicate fraction of TTHMs that are removed by the aeration system.

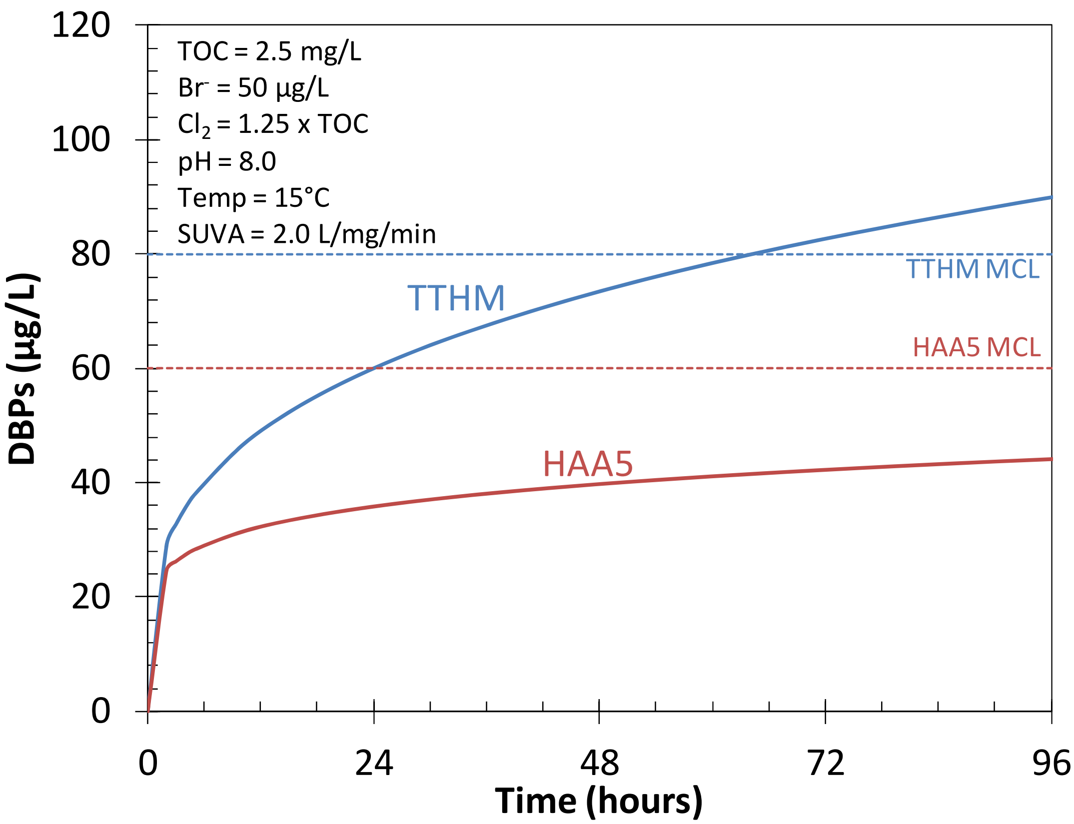


Figure 4-3 TTHM and HAA5 formation as a function of time in a hypothetical water sample as predicted by the WTP Model

The seven conditions that were tested were listed earlier in Chapter 2. Table 4-4 shows the schedule and the actual dates when each of the seven conditions were tested. Originally, it was intended that the test conditions will be operated from 1 through 7 as listed in Table 4-4. However, due to some logistical issues that required troubleshooting, the order of the seven conditions were switched, and conditions were tested on the dates listed in Table 4-4. After completion of the testing of seven test conditions on January 6, 2015, the tests were extended through January 25, 2015, when several of the conditions were repeated for a 3-4 day duration.

Table 4-4 Schedule of demonstration testing

Test Condition	Aeration Approach	Ventilation	Dates
1 (Baseline)	None	Passive	11/12/14 – 11/25/14
2	None	Active	12/30/14 – 1/6/15
3	Tank mixing	Active	11/25/14 – 12/2/14
4	Surface aeration	Active	12/16/14 – 12/23/14
5	Surface aeration	Passive	12/23/14 – 12/30/14
6	Spray system	Active	12/2/14 – 12/9/14
7	Spray system	Passive	12/9/14 – 12/16/14
	Various repeat tests	Active and Passive	1/6/15 – 1/24/15

As described earlier, TTHM data were collected through multiple field and laboratory samples during the demonstration testing period. Among them, the largest number of samples were analyzed with the AMS THM100™ analyzer. This analyzer was connected online to measure TTHMs in the clearwell effluent samples. Figure 4-4 shows a graph of all TTHM data analyzed by the AMS instrument between November 2014 and January 2015. The duration of testing of each of the seven test conditions are also shown on Figure 4-4.

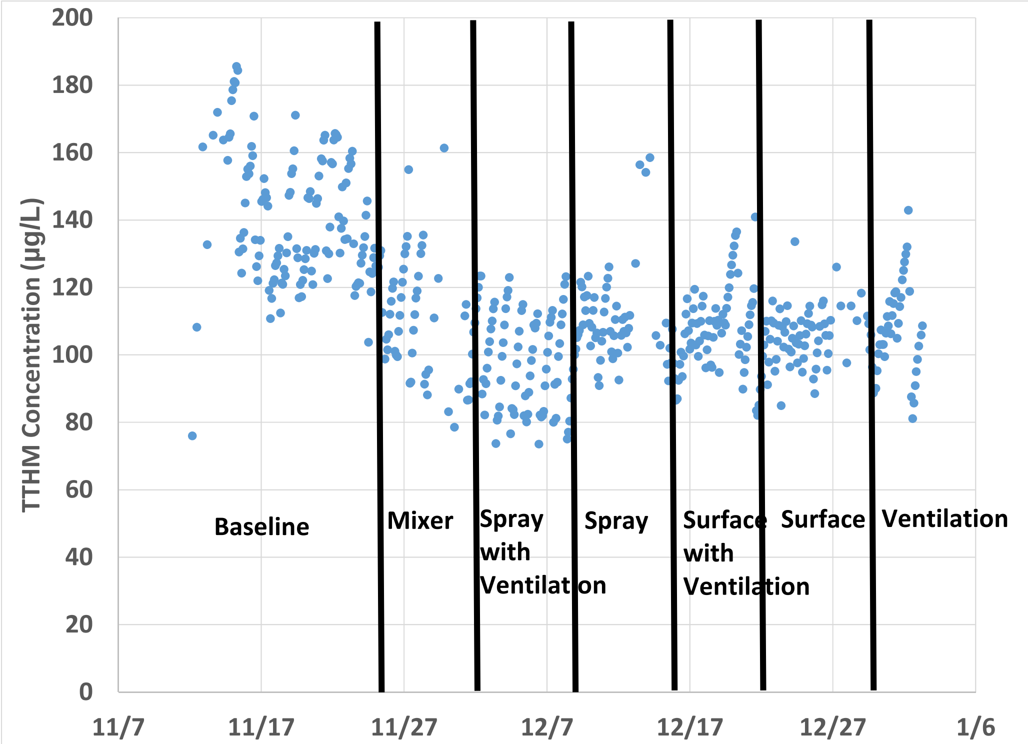


Figure 4-4 AMS THM 100™ data (clearwell effluent) and dates of testing of the seven test conditions

Baseline Testing

As seen in Figure 4-4, baseline testing was conducted between November 12 and November 25, 2014. During this period, while all the aeration equipment had been installed, none of it was operational. The only difference between the WTP's normal operations, and modifications due to the aeration testing, was that the point of chlorine addition was moved ahead of the WTP to the raw water.

Figure 4-5 shows the TTHM concentrations in the WTP effluent and the clearwell effluent during the baseline testing period. As can be seen in the figure, the TTHM concentrations in the WTP effluent varied between 60 and 100 µg/L during the baseline testing period. The TTHM concentrations in the clearwell effluent varied between 120 and 180 µg/L during the baseline testing period. This shows that the TTHM formation reaction is incomplete in the WTP effluent and TTHM concentrations increased between 30 and 60 percent in the clearwell.

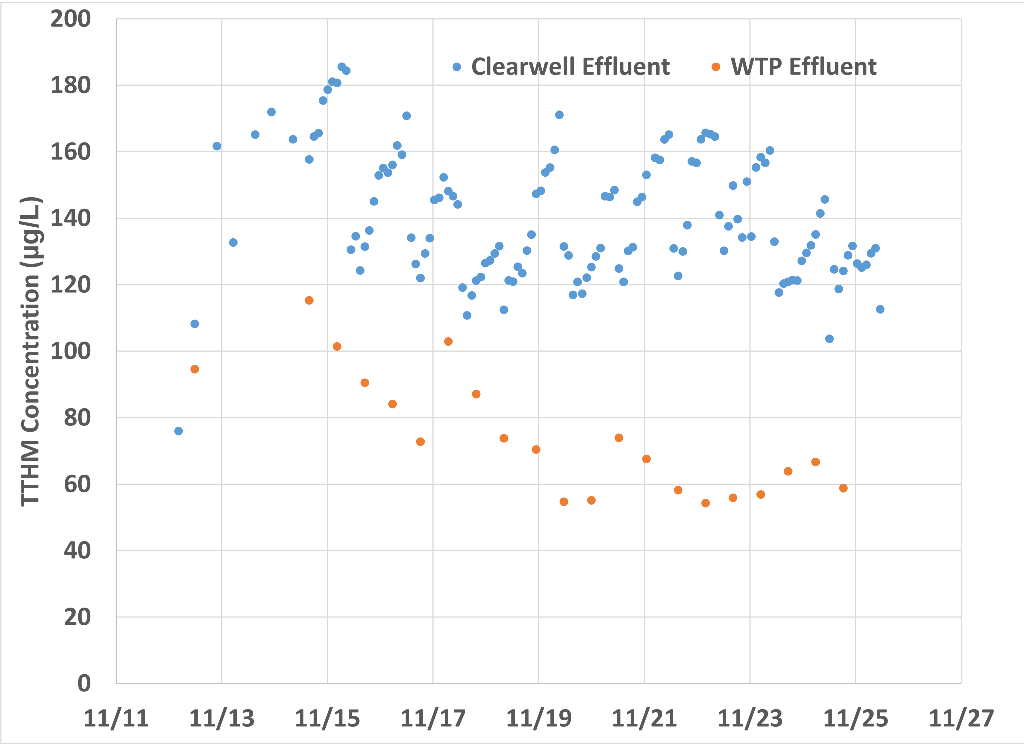


Figure 4-5 TTHM concentrations in the WTP effluent and clearwell effluent during baseline testing period

A closer look at the TTHM concentrations in the clearwell effluent in Figure 4-5 shows a "saw-tooth" effect – meaning daily (nightly) trends of gradual increase of TTHM concentrations followed by a sharp decrease. Figure 4-6 illustrates this observation – it shows the same clearwell effluent TTHM data as shown in Figure 4-5, but only for two days between November 16 and November 18, 2014. The time-stamps on each data point are not shown in Figure 4-6, but it was observed that the TTHM concentrations in the clearwell increased and gradually flattened out through the night with increased detention time in the clearwell. This was followed by a sharp drop in TTHM concentrations the next morning. This drop was initiated after the WTP had been switched on the following day. The "fresh" water that was pumped by the WTP into the clearwell had considerably lower TTHM concentrations, and it resulted in dilution of the water that was present overnight in the clearwell, which had higher TTHM concentrations. This observation was consistent throughout the baseline testing period.

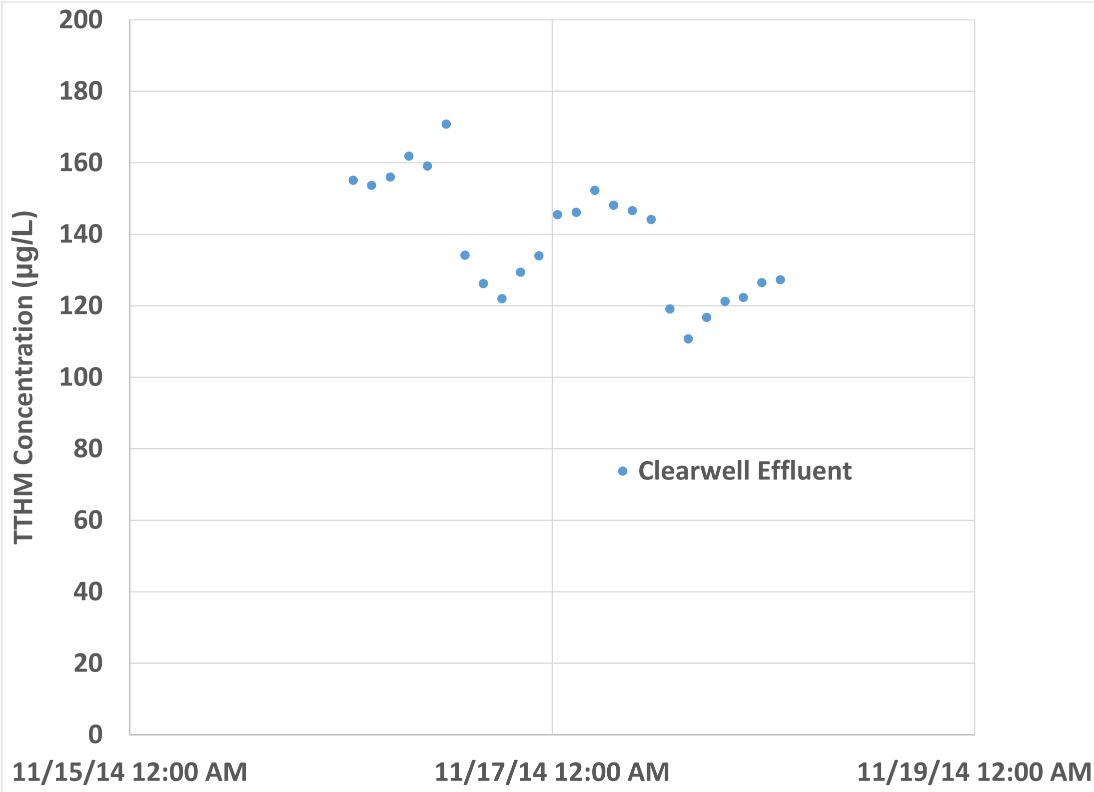


Figure 4-6 TTHM concentrations in the clearwell effluent between 11/16/14 and 11/18/14

After the completion of all the different test conditions between November and January, some conditions were repeated for a few days to generate duplicate data, or to confirm observed trends. During this process, baseline conditions were repeated between January 12 and 15, and again between January 18 and 22. The clearwell effluent TTHM concentrations during the repeat testing of the baseline conditions are shown in Figure 4-7. As can be seen from the comparison of Figure 4-7 to Figure 4-5, the TTHM concentrations under baseline conditions testing in January were lower than baseline TTHM concentrations observed in November. The baseline TTHM concentrations in the clearwell effluent in January ranged between 80 and 120 µg/L. The reason for the lower TTHM concentrations in January were lower water temperatures (6-8°C) compared to water temperatures (12-14°C) in November. However, all other trends of TTHM formation, and diurnal saw-tooth curves due to dilution with fresh water were consistent between the November and January observations.

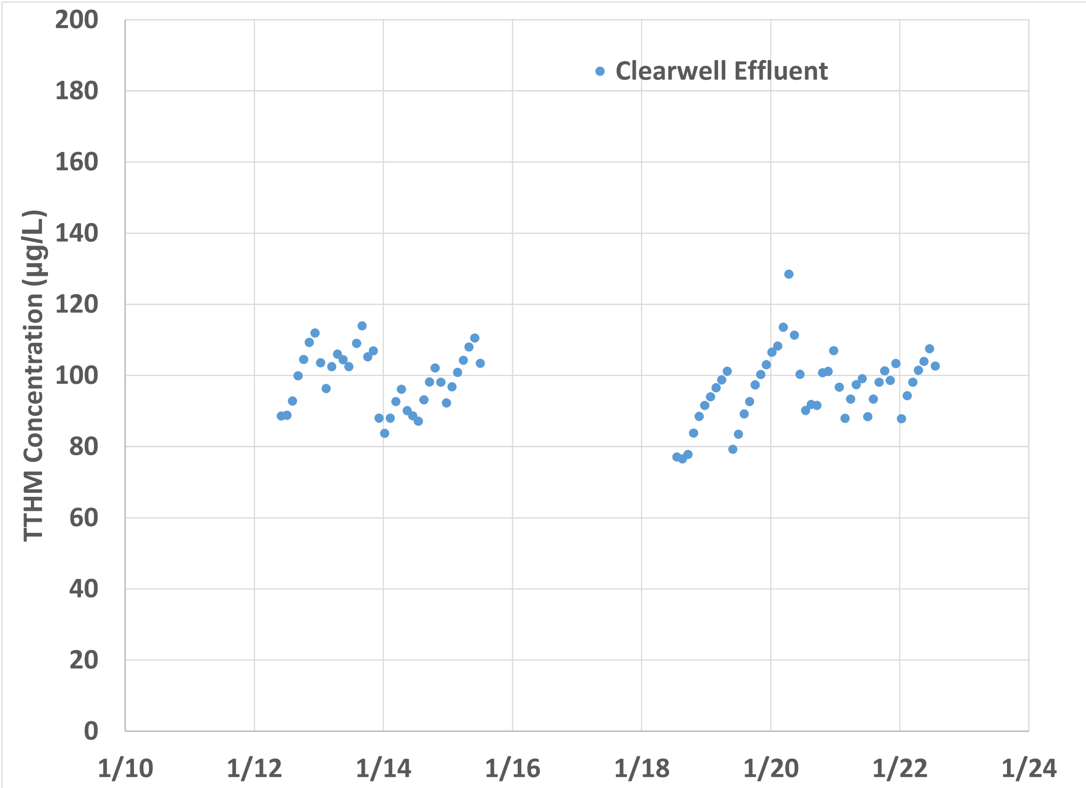


Figure 4-7 TTHM concentrations in the clearwell effluent during repeat baseline testing in January

Spray Aeration

The spray aeration testing was conducted for two weeks between December 2 and December 16, 2014. The first week of testing included active ventilation, while the second week of testing was done with passive ventilation. The spray aeration pump was operated at a single flow rate and operating pressure throughout this period – no change in operating conditions were performed.

Figures 4-8 and 4-9 show the TTHM concentrations in the clearwell effluent during spray aeration testing with active ventilation and passive ventilation respectively. The y-axis of Figures 4-8 and 4-9 have the same scale as Figure 4-5 that shows the TTHM concentrations in the clearwell effluent during the baseline testing period. A comparison of Figures 4-8 and 4-9 with Figure 4-5 indicates that TTHM concentrations in the clearwell effluent during spray aeration testing (both with active and passive ventilation) are approximately 25 to 30 percent lower than corresponding TTHM concentrations in the clearwell effluent during baseline testing period. As shown in Figure 4-9, a few of the TTHM concentrations on December 14, 2014 were higher than the rest of the TTHM concentrations observed during that week of testing. The exact cause for this exceedance was not known, however, it is possible that the spray aeration system may have been accidentally switched off for a brief period during that time.

Similar saw-tooth effect in the clearwell effluent TTHM concentrations are observed in Figures 4-8 and 4-9 as was seen in Figure 4-5. There are two specific factors that cause the saw-tooth appearance of the plots in Figures 4-8 and 4-9, and the observed results are due a combination of both factors. The two factors are as follows:

1. When the WTP and the high service pumps are shut down in the evening, there is very little flow through the 6-inch pipe that connects the clearwell to the high service pumps. The clearwell effluent TTHM sampling port was constructed on this 6-inch pipeline. During overnight hours, as there is very little flow through this pipe, the observed TTHM concentrations do not represent actual TTHM concentrations in the clearwell, but are representative of the TTHM concentrations present in the stagnant water in the 6-inch pipe. When the high service pumps are switched on the following morning, the overnight water is pumped through the high service pumps, and the TTHM concentrations measured represent TTHM concentrations in the clearwell with the spray aeration system in operation. Note that the spray aeration system was operational continuously during day and night during the entire period of testing.
2. As discussed earlier with baseline testing, when the WTP is switched on every morning, "fresh" water, with lower TTHM concentrations, enter the clearwell, and dilute the overnight water in the clearwell that has higher TTHM concentrations. As a result, the measured lower TTHM concentrations in the clearwell effluent in the morning represent the dilution of water with higher TTHMs by water with lower TTHM concentrations.

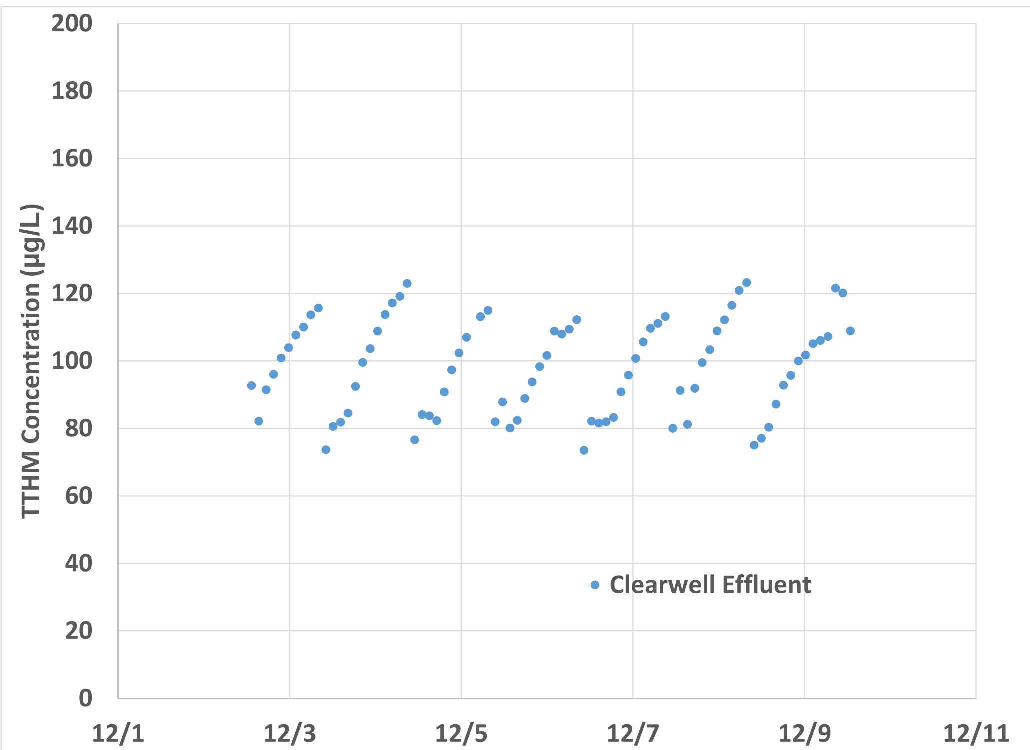


Figure 4-8 TTHM concentrations in the clearwell effluent during spray aeration with active ventilation testing

Given those two independent factors, there is a difference between "TTHM removal by the spray aeration system", and "overall TTHM reduction through the clearwell". A different analyses approach needed to be adopted to understand the "actual" TTHM removal by the spray aeration system. This analysis approach will be discussed here. However, first, it is important to quantify the overall TTHM reduction through the clearwell as a result of the spray aeration system operation, both with and without ventilation.

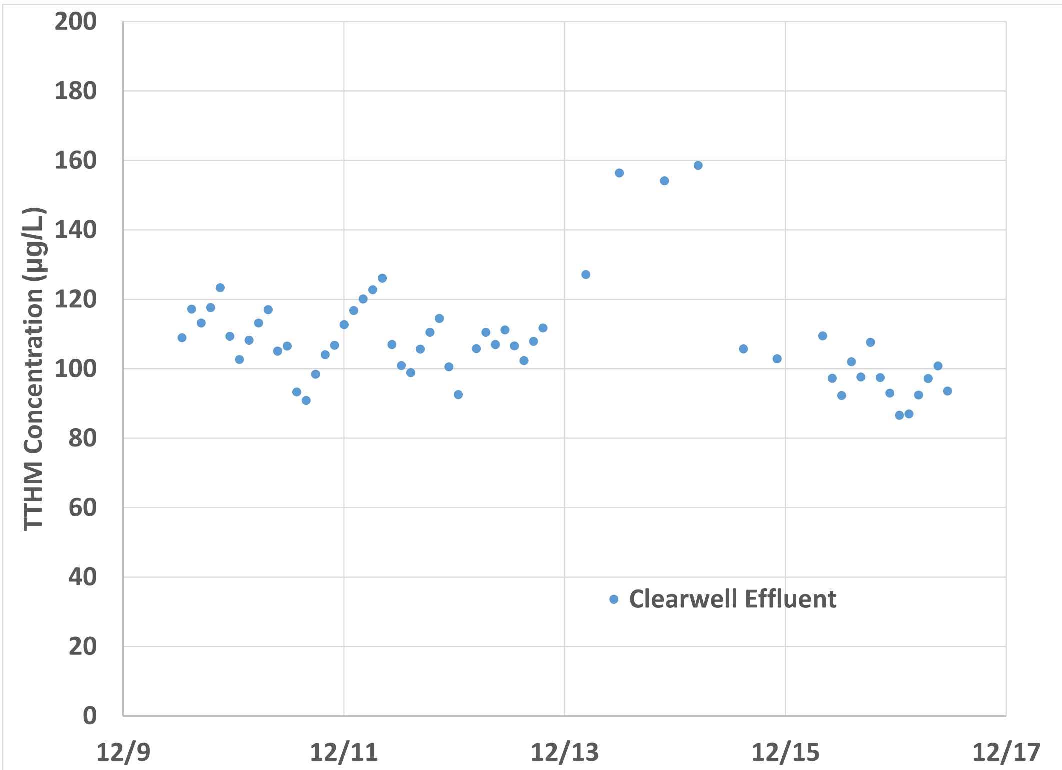


Figure 4-9 TTHM concentrations in the clearwell effluent during spray aeration with passive ventilation testing

Figure 4-10 shows a box and whisker plot that compares the overall TTHM reduction with spray aeration with active and passive ventilation with the baseline conditions. The median TTHM concentrations with spray aeration with active ventilation and passive ventilation are 99.6 µg/L and 105.8 µg/L respectively. This compares to a median TTHM concentration of 134.5 µg/L during baseline condition testing. As such, spray aeration with active and passive ventilation result in 25.9% and 21.3% overall TTHM reduction compared to baseline conditions. However, this analysis does not accurately represent actual TTHM removal by the spray aeration system because:

- During daytime hours, the hydraulic residence time through the clearwell varies continuously and significantly. As such TTHM removal by spray aeration cannot be quantified accurately
- There is significant formation of TTHM inside the clearwell due to reaction between chlorine and organics. As discussed previously, the formation of new TTHMs offsets the TTHM removal by the spray aeration system

- When the WTP is started up in the morning, fresh water with lower TTHM concentrations mixes with the water that was present overnight in the clearwell, thereby diluting it. As such, TTHM removal via spray aeration cannot be quantified accurately.

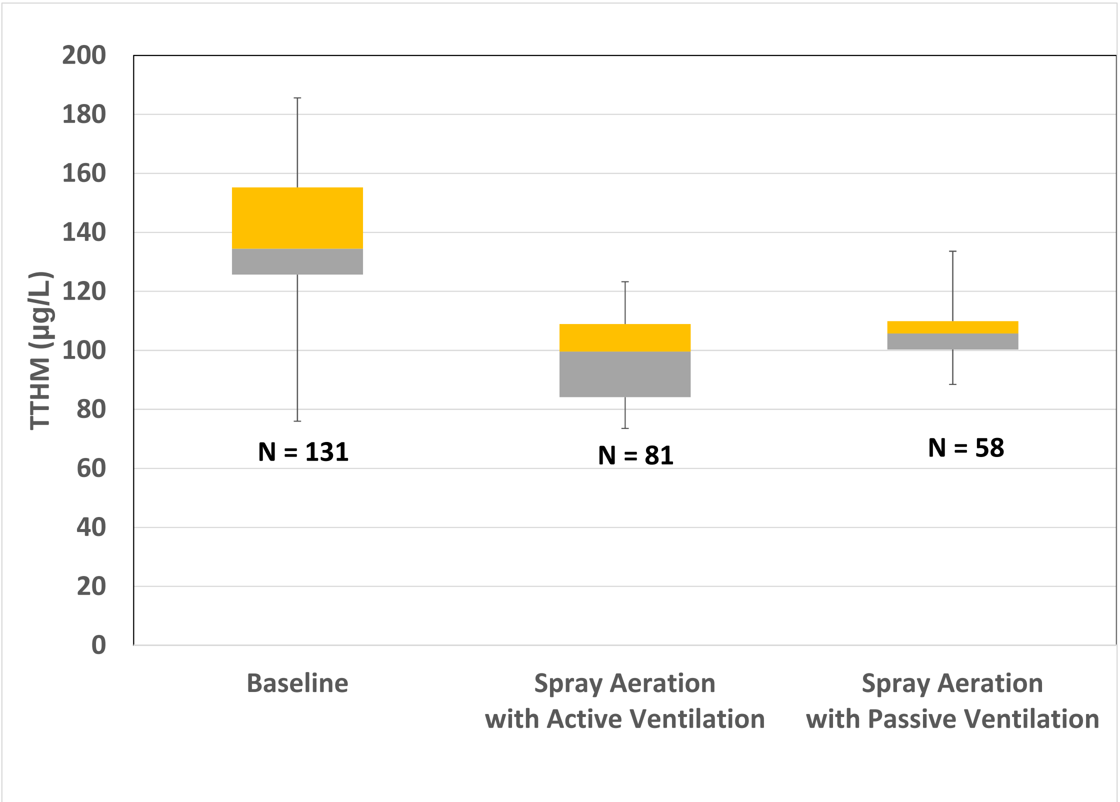


Figure 4-10 Box and whiskers plot comparing spray aeration with active and passive ventilation with baseline testing conditions

In order to decouple the different TTHM formation and removal mechanisms, a different analytical approach was adopted. Several assumptions needed to be made to perform this analysis. These assumptions are listed below:

- During the daytime hours when both the WTP and the high service pumps are operational, either continuously, or intermittently, the hydraulic residence time within the clearwell changes continuously. So determination of effectiveness of spray aeration is extremely difficult. As such, all TTHM data recorded during daytime hours were excluded from the analyses.
- During the evening and night hours, the WTP and the high service pumps remained switched off. During this period, there was no water flow into or out of the clearwell. During this time, the clearwell can be considered as a batch reactor for the determination of spray aeration effectiveness.
- Given that there is very little flow through the 6-inch pipe carrying water from the clearwell to the high service pumps during evening hours, the water present in that 6-inch pipe is not representative of water quality within the clearwell. Rather, that water represents TTHM

concentrations that are/ may be formed in the clearwell in the absence of any aeration system operation. Water samples were drawn from that 6-inch pipe every 4 hours and analyzed by the online TTHM analyzer. These TTHM concentrations represent TTHM formation in the clearwell in the absence of any aeration system operation.

- When the high service pumps are switched on in the morning, the water that was present overnight in the clearwell are sampled and analyzed by the online TTHM analyzer. The first sample collected and analyzed by the online analyzer represent the water quality that was present within the clearwell and was impacted by the aeration system.

Based on these assumptions, TTHM removal by spray aeration were determined. Figures 4-11 and 4-12 have been developed with the following data points:

- The blue data-points represent the TTHM concentrations observed in the "final" overnight sample prior to the switching on of the high service pumps in the following morning
- The orange data-points represent the TTHM concentrations in the "first" water sample analyzed by the online THM analyzer after the high service pumps were switched on every morning.
- The green data points represent the percentage removal of TTHMs

Based on this analysis, it can be inferred that the spray aeration system with active ventilation removed approximately 34.2 percent TTHM from the clearwell, whereas the spray aeration system with passive ventilation removed approximately 19.1 percent TTHM from the clearwell. These are the best estimates of TTHM removal by the spray aeration system. Even this analysis is not completely accurate, because usually, the WTP would be switched on for a while prior to the high service pumps being operated, and fresh water entering the clearwell mixing with spray aeration treated water, and as such altering the TTHM concentrations present in the water that was stored overnight in the clearwell.

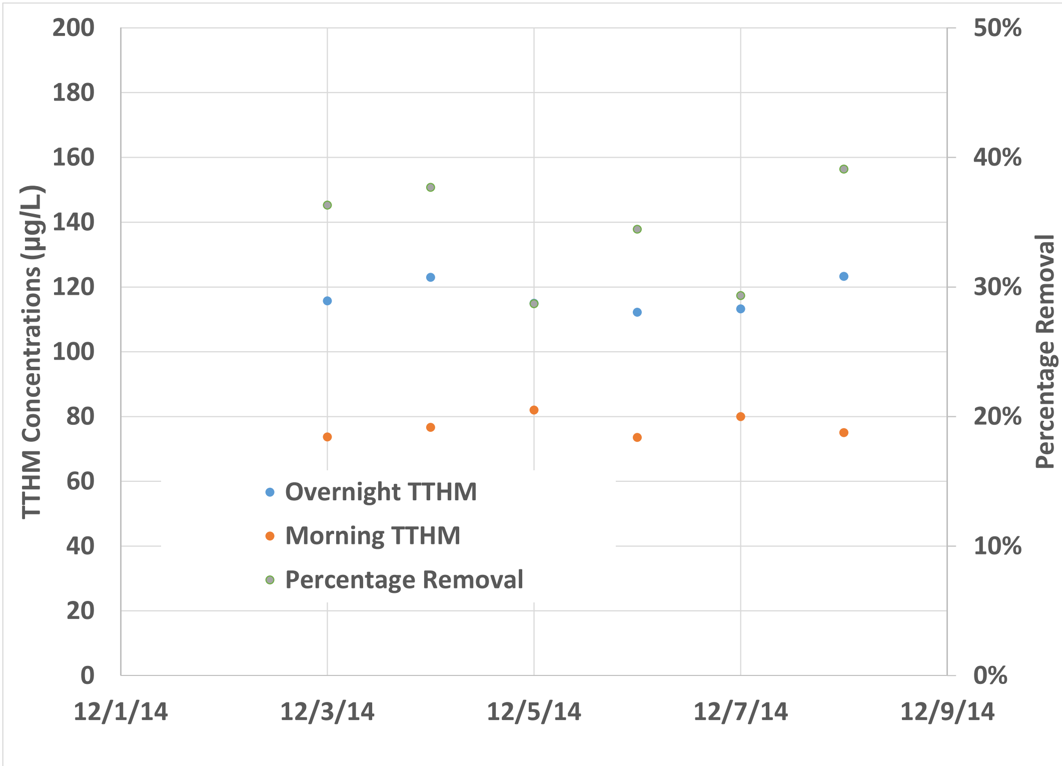


Figure 4-11 Actual TTHM removal by spray aeration with active ventilation

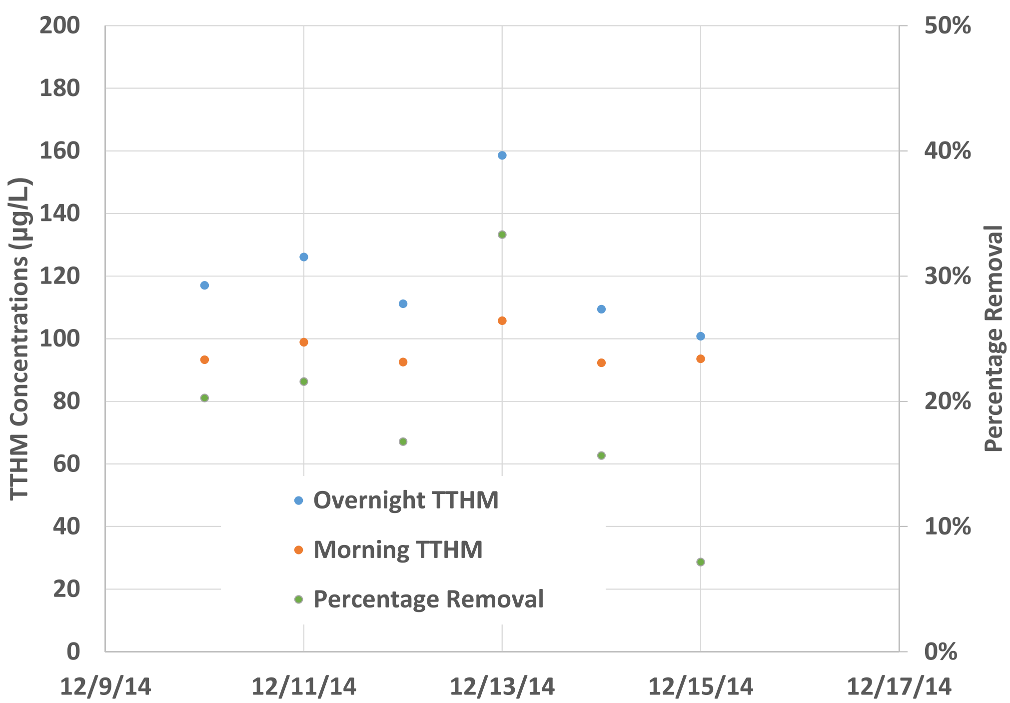


Figure 4-12 Actual TTHM removal by spray aeration with passive ventilation

Surface Aeration

The surface aeration testing was conducted for two weeks between December 16 and December 30, 2014. The first week of testing included active ventilation, while the second week of testing was done with passive ventilation. The surface aerator was operated at a single set point throughout this period – no changes in operating conditions were performed.

Figures 4-13 and 4-14 show the TTHM concentrations in the clearwell effluent during surface aeration testing with active ventilation and passive ventilation respectively. The absolute values of the TTHM concentrations in the clearwell effluent during surface aeration testing were similar to the observed TTHM concentrations during spray aeration testing, and were considerably lower (by 20 to 25 percent) than the TTHM concentrations during baseline testing.

Similar saw-tooth effect in the clearwell effluent TTHM concentrations are observed in Figures 4-13 and 4-14 as was seen in Figures 4-5, 4-8, and 4-9. This was due to stagnation of water in the 6-inch pipe during overnight hours, and influence of fresh water with lower TTHMs during the morning hours, similar to the discussion presented earlier for spray aeration.

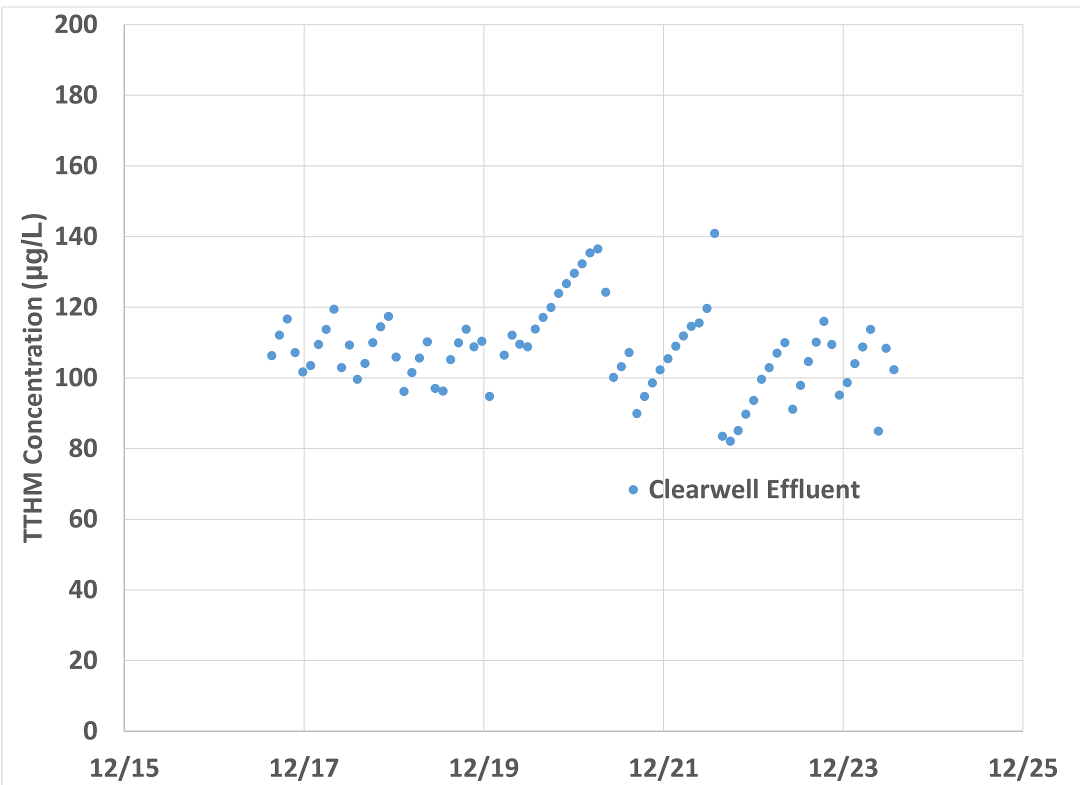


Figure 4-13 TTHM concentrations in the clearwell effluent during surface aeration with active ventilation testing

The overall reduction of TTHM concentrations through the clearwell during surface aeration operation can be summarized in a box and whisker plot shown in Figure 4-15. The median TTHM concentrations with surface aeration with active ventilation and passive ventilation are 107.8 µg/L and 106.5 µg/L respectively. This compares to a median TTHM concentration of 134.5 µg/L during baseline condition testing. As such, surface aeration with active and passive ventilation result in 19.9% and 20.8% overall TTHM reduction compared to baseline conditions. Compared to the spray aeration testing, the overall reduction of TTHM concentrations through the clearwell during surface aeration testing was slightly lower. Slightly colder water temperatures during surface aeration testing compared to during spray aeration testing could have contributed to the reduced effectiveness of the surface aerator.

However, as discussed earlier, the overall reduction of TTHM concentrations through the clearwell are the result of a combination of mechanisms such as hydraulic residence time in the clearwell, TTHM formation rate, and dilution of clearwell water with fresh water pumped by the WTP. As such, the overall reduction of TTHM concentrations in the clearwell effluent are not representative of actual TTHM removal achieved by the surface aeration system.

A similar approach to the one described for spray aeration was adopted to estimate TTHM removal achieved by the surface aeration system. The results of this analyses are shown in Figures 4-16 (surface aeration with active ventilation) and 4-17 (surface aeration with passive ventilation). Based on these analyses, it can be inferred that surface aeration with active ventilation removed 21.8 percent of clearwell TTHMs and surface aeration with passive ventilation removed 21.6 percent of clearwell TTHMs. Similar to the spray aeration discussion, this analysis is not completely accurate because there was some dilution of overnight clearwell water with fresh WTP pumped water.

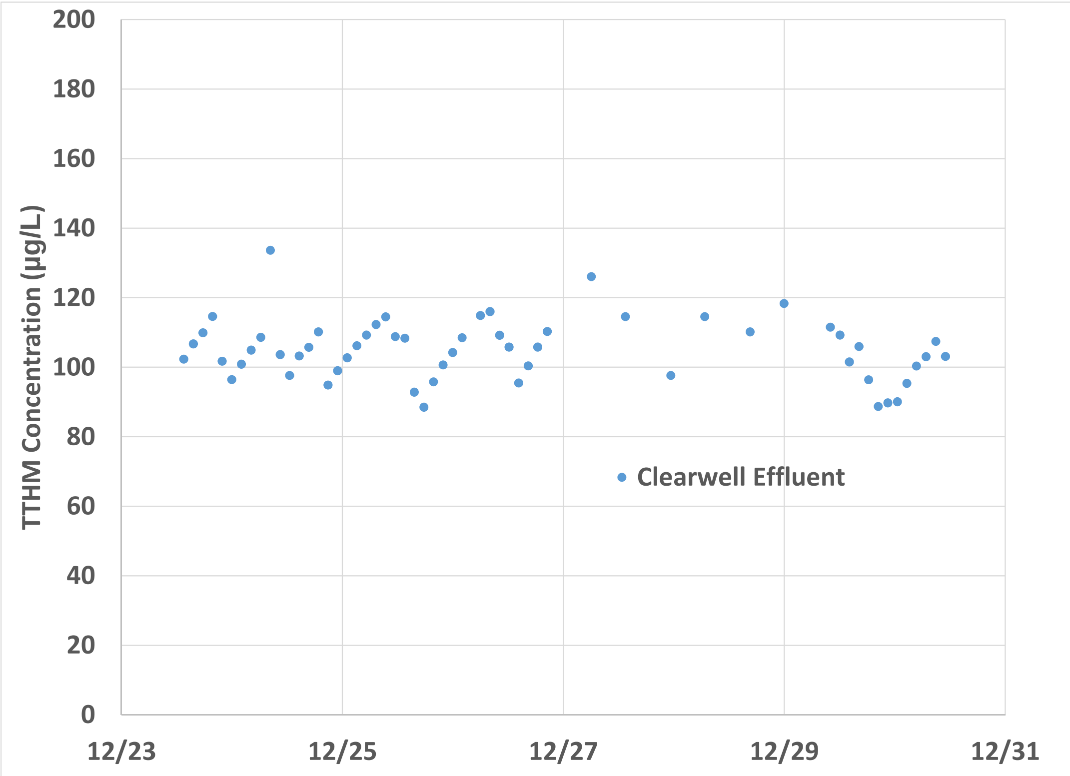


Figure 4-14 TTHM concentrations in the clearwell effluent during surface aeration with passive ventilation testing

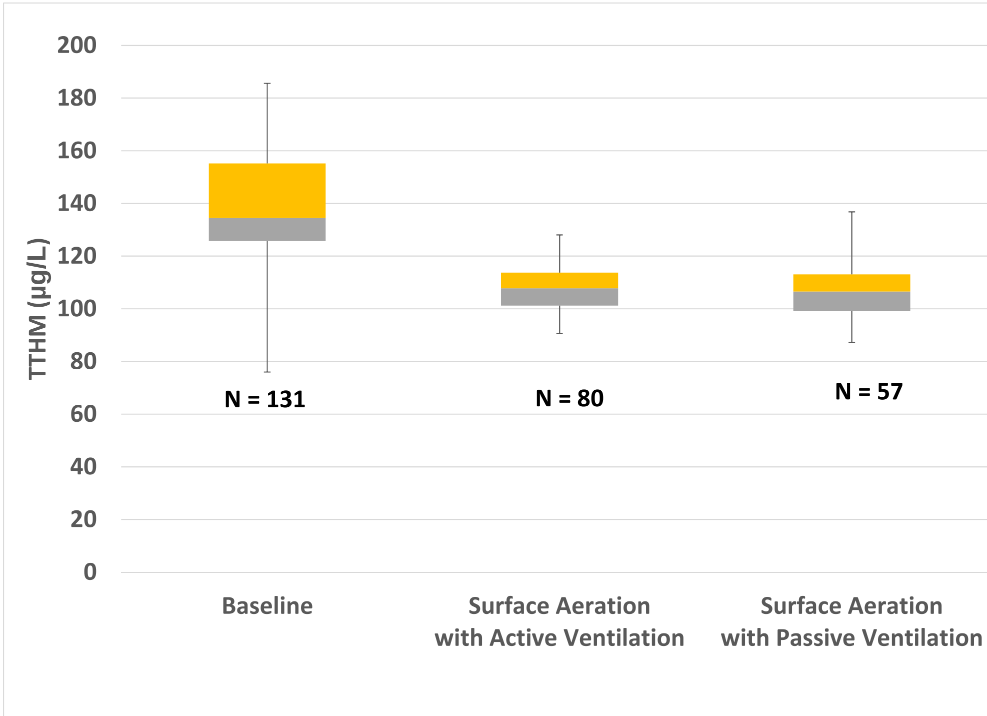


Figure 4-15 Box and whiskers plot comparing surface aeration with active and passive ventilation with baseline testing conditions

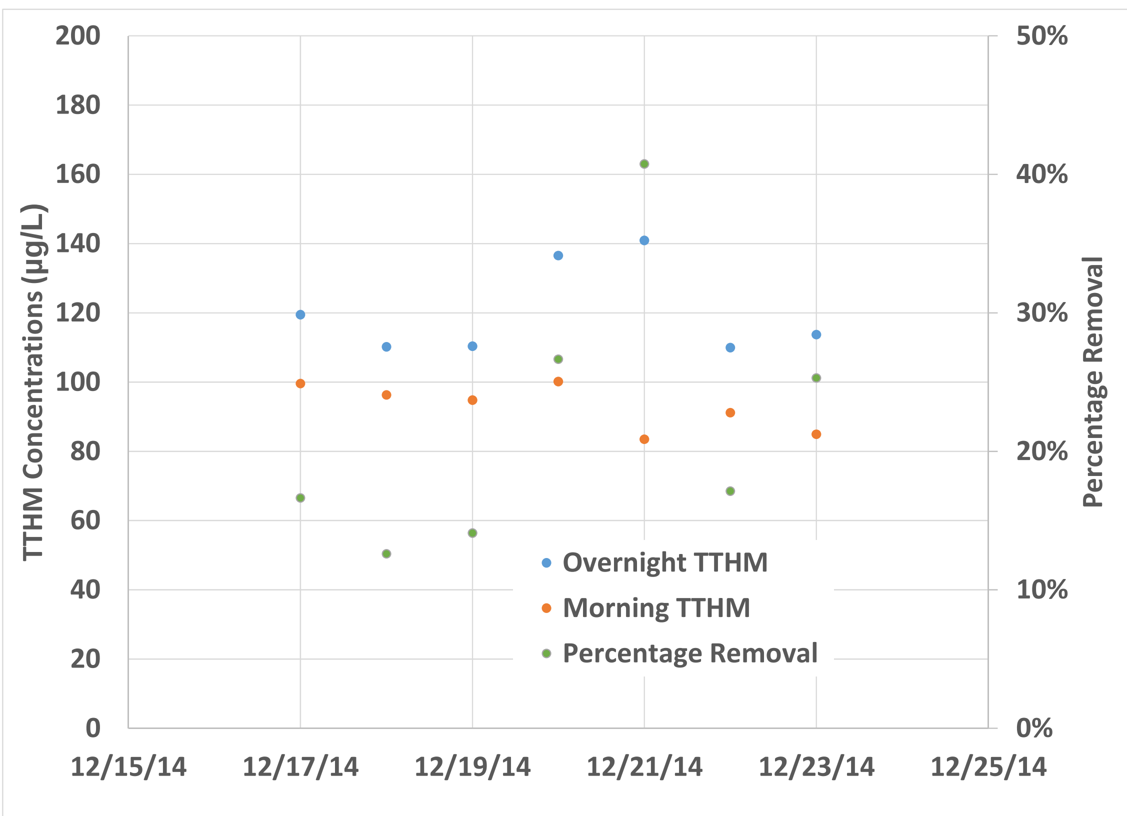


Figure 4-16 Actual TTHM removal by surface aeration with active ventilation

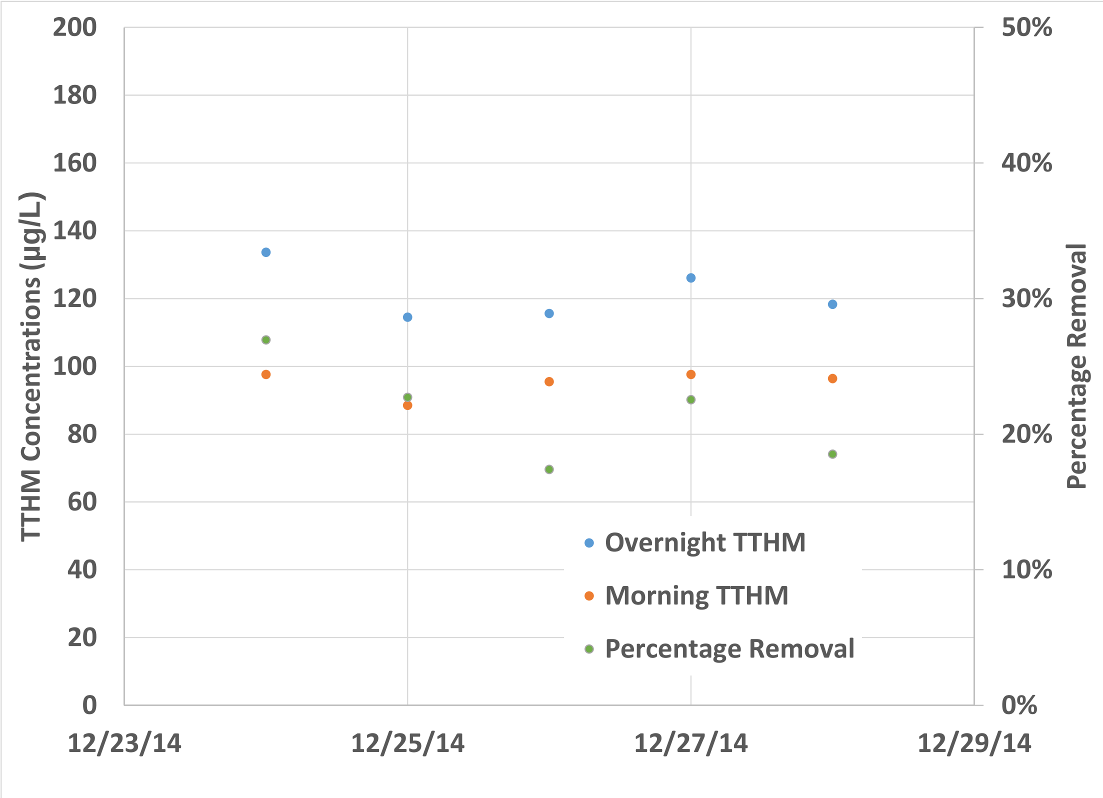


Figure 4-17 Actual TTHM removal by surface aeration with passive ventilation

Mixer

The mixer testing was conducted for one week between November 25 and December 2, 2014. The mixer was operated at a single set point throughout this period – no changes in operating conditions were performed.

Figure 4-18 shows the TTHM concentrations in the clearwell effluent during mixer testing. The figure shows that the TTHM concentration trends during the mixer testing were similar to that of the spray aeration and surface aeration testing, even though the overall reduction of TTHMs through the clearwell was slightly lower during this test phase compared to spray and surface aeration testing. The saw-tooth effect in the clearwell effluent TTHM concentrations was due to stagnation of water in the 6-inch high service pumps pipe during overnight hours, and influence of fresh water with lower TTHMs during the morning hours.

Similar to the analyses performed for spray and surface aeration, the actual TTHM removal by the mixer was calculated as shown in Figure 4-19. The average TTHM removal achieved by the mixer during the one week period was approximately 7 percent. As seen in Figure 4-19, some of the TTHM percentage reduction values are less than zero. This is due to the fact that TTHM concentrations in the clearwell continued to increase overnight and was not removed by the mixer, and thus reflected in the higher morning TTHM concentrations.

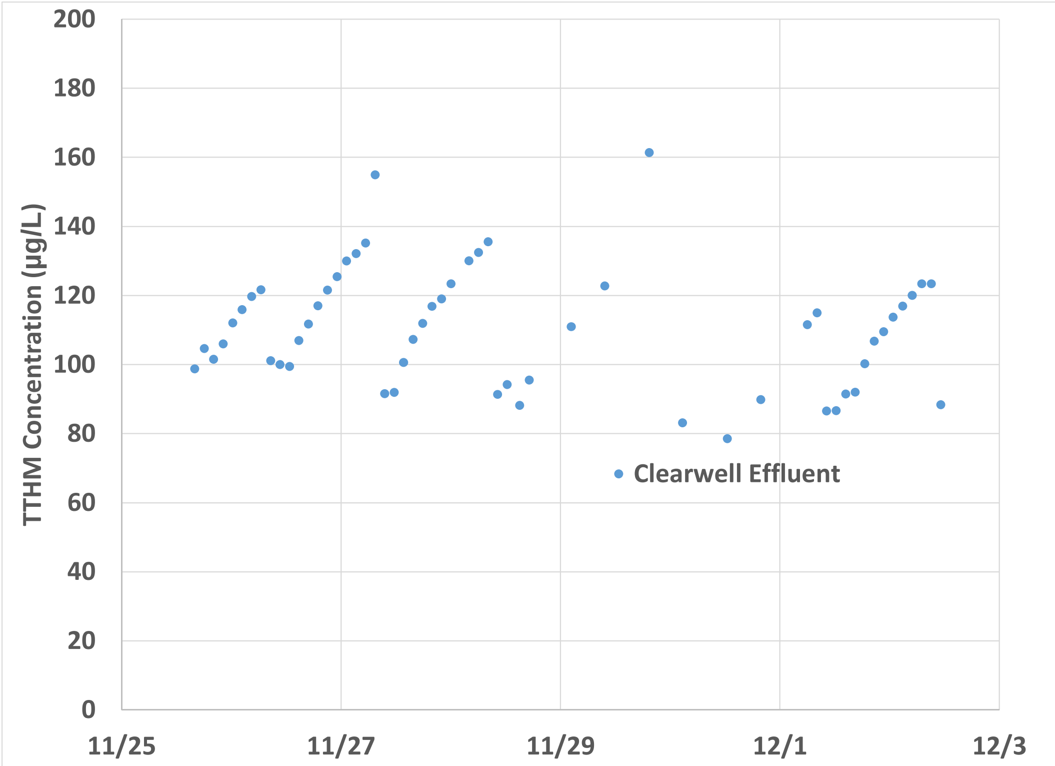


Figure 4-18 TTHM concentrations in the clearwell effluent during mixer testing

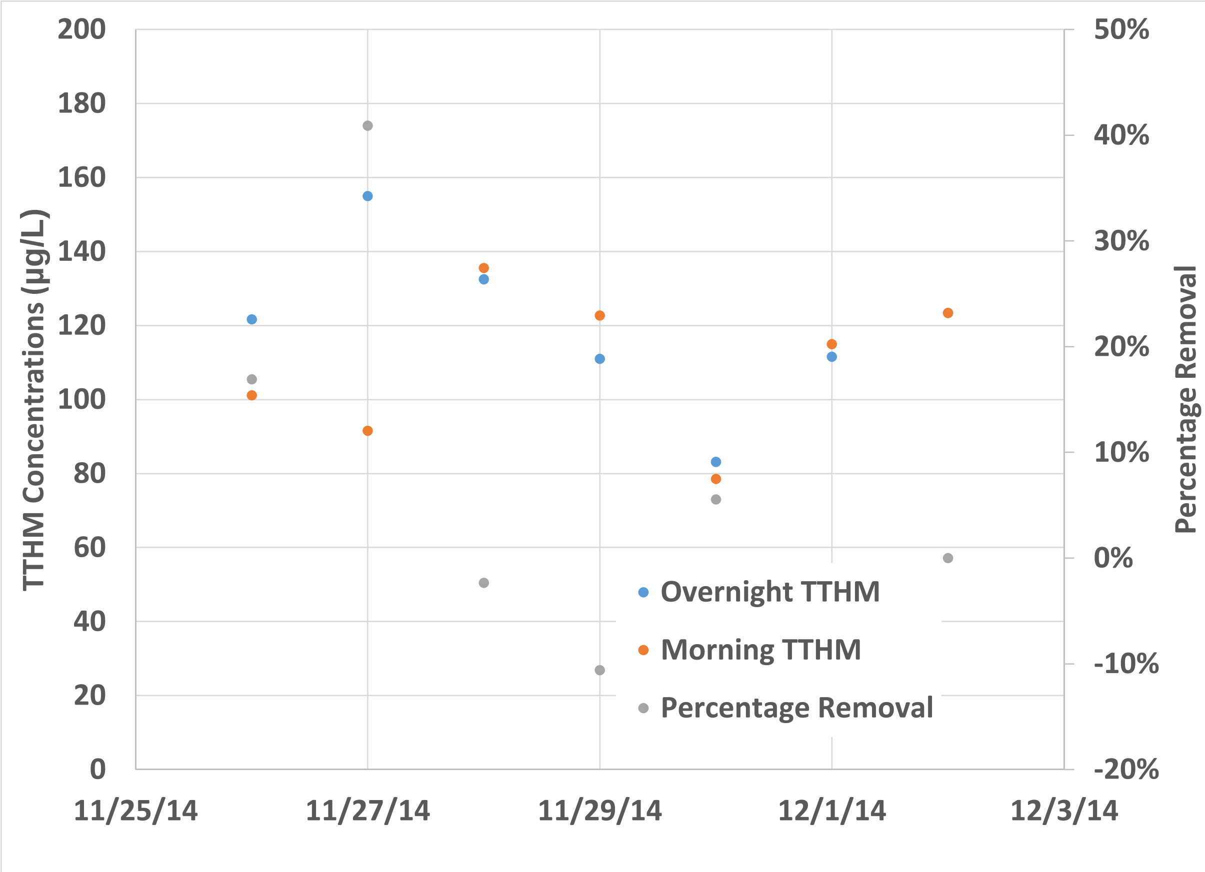


Figure 4-19 Actual TTHM removal by mixer

Ventilation

The ventilation testing was conducted for one week between December 30, 2014 and January 6, 2015. The ventilation fan was operated at a single set point throughout this period – no changes in operating conditions were performed.

Figure 4-20 shows the TTHM concentrations in the clearwell effluent during the ventilation testing. The TTHM concentrations in the clearwell effluent during ventilation testing were very similar to the TTHM concentrations in the clearwell effluent during mixer testing. Appreciable TTHM removal was not observed during testing of the ventilation system alone, when compared to the repeat baseline testing in January (Figure 4-7).

Similar to the analyses performed for spray aeration, surface aeration, and mixer, the actual TTHM removal by ventilation was calculated as shown in Figure 4-21. The average TTHM removal achieved by ventilation during the one week period was approximately 4 percent. Similar to the mixer observation, as seen in Figure 4-21, some of the TTHM percentage reduction values are less than zero. This is due to the fact that TTHM concentrations in the clearwell continued to increase overnight and was not removed by ventilation, and thus reflected in the higher morning TTHM concentrations.

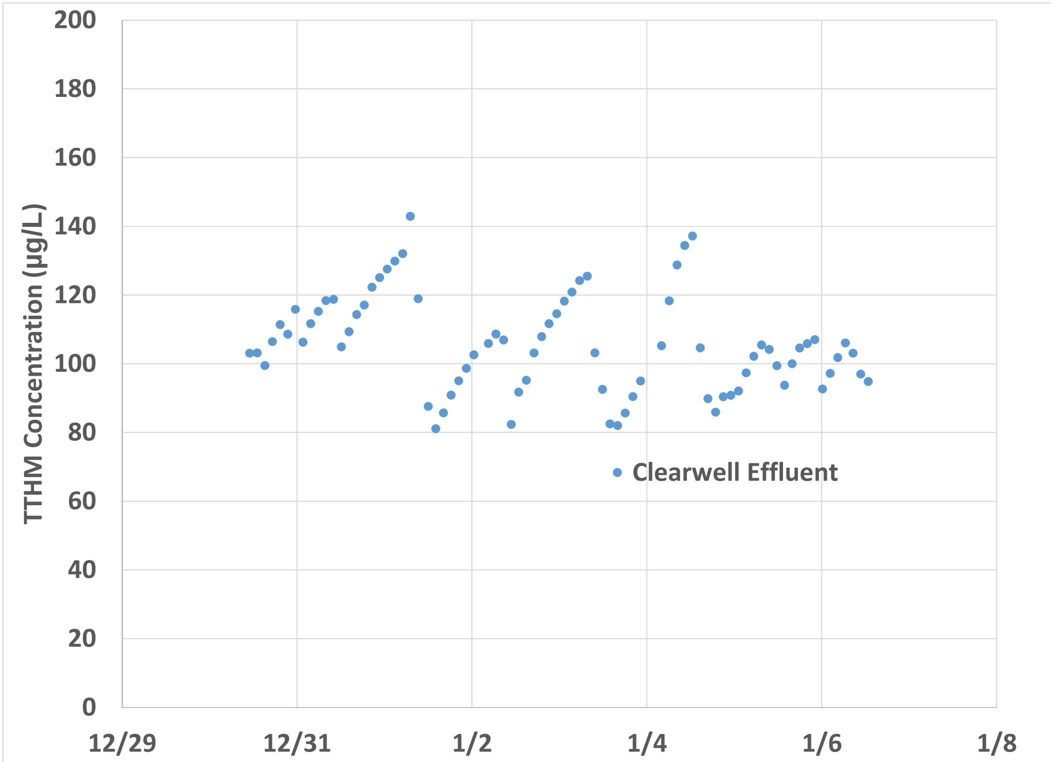


Figure 4-20 TTHM concentrations in the clearwell effluent during ventilation testing

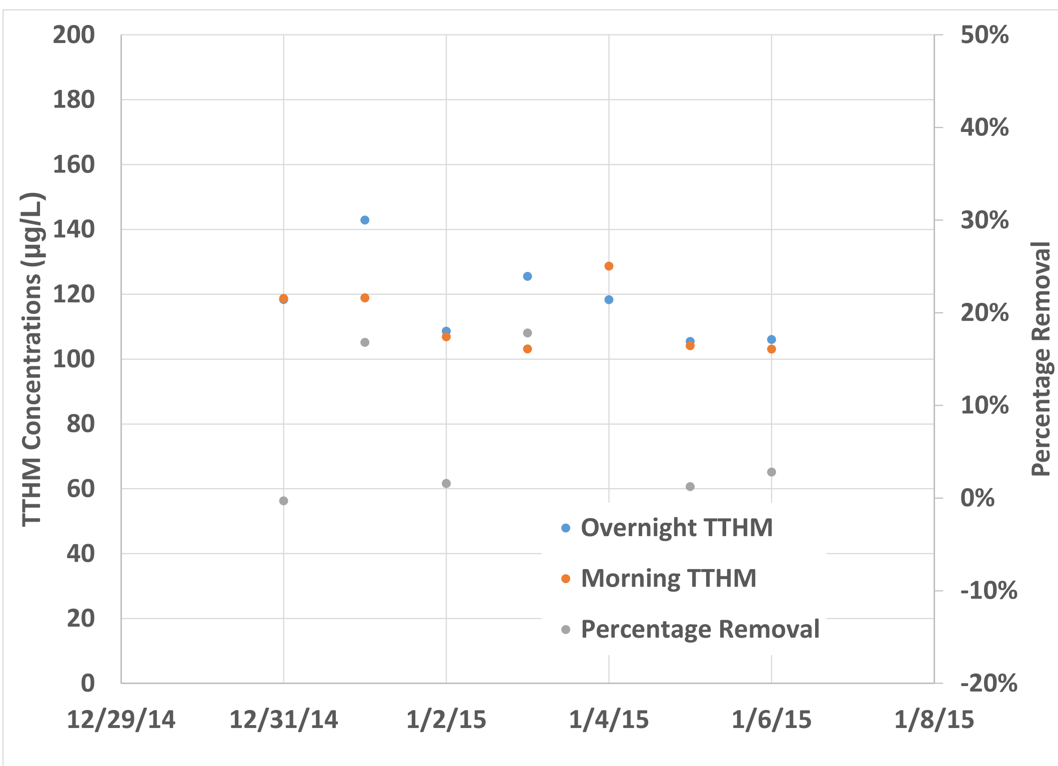


Figure 4-21 Actual TTHM removal by ventilation

TTHM Speciation

In addition to overall TTHM reduction, insights were also gained on the removal of individual THM species during aeration demonstration testing. It is well established that chloroform is more volatile than brominated THM species and bromoform is least volatile among the four THM species. As such, TTHM speciation was analyzed on all results obtained through the demonstration testing, including WTP effluent samples and clearwell effluent samples.

Figure 4-22 shows a comparison of the THM speciation between the WTP effluent samples, and the clearwell effluent samples during baseline testing and spray aeration testing. Chloroform comprises approximately 56% of TTHM in the WTP effluent sample. Dichlorobromomethane and dibromochloromethane comprise approximately 28% and 14% of TTHM, while bromoform comprises only 2% of TTHM. In comparison, in the clearwell effluent samples, chloroform comprises only 44% of TTHM. The two brominated species make up approximately 47% while bromoform comprises of the remaining 9% of the TTHMs. This is indicative of the fact that initial formation of chloroform is quicker than the brominated species. However, over a longer period, there is a higher percentage increase in the brominated species than in chloroform concentration.

Comparing the baseline to the spray aeration THM speciation in Figure 4-22, it can be seen that chloroform comprises approximately 41% of the TTHM in the spray aeration treated water. The two brominated species comprise approximately 57% while bromoform makes up the remaining 2% of the spray aeration treated TTHMs. Thus, it can be inferred that the THM speciation in the spray aeration treated water is not significantly different than the THM speciation under baseline conditions, even though there is a marginally higher rate of chloroform removal by spray aeration compared to the three brominated species. It is hypothesized that the reduction in bromoform fraction from 9% of TTHMs under the baseline conditions to 2% under spray aeration conditions is not due to higher stripping of bromoform by aeration, but rather conversion of bromoform to other brominated species. Another possibility is that chlorinated THMs are intermediary products in the bromoform formation process, and the stripping of chlorinated THMs prevents or reduces the formation of bromoform. The THM speciation during surface aeration testing is not shown here, but the THM speciation in surface aeration treated water was similar to THM speciation in spray aeration treated water.

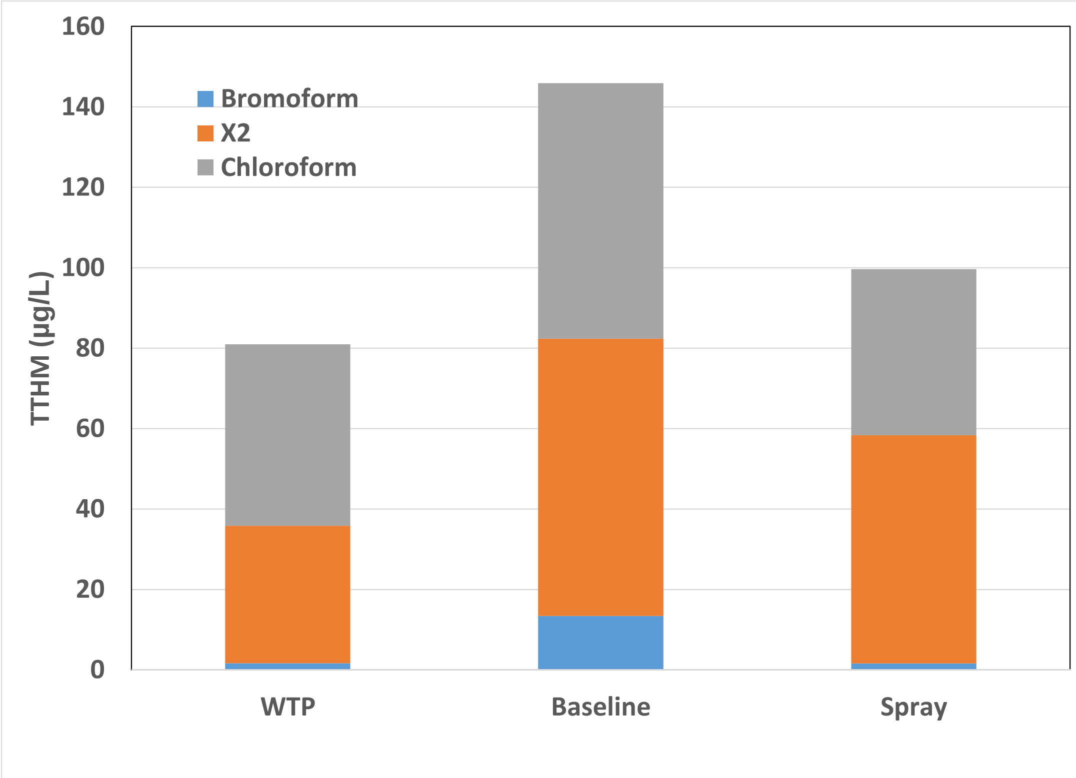


Figure 4-22 TTHM speciation in the WTP effluent, and clearwell effluent samples during baseline testing and spray aeration testing

Comparison of Field and Laboratory THM Analysis

As discussed earlier, two field analyzers as well as two laboratories were used for analyses of TTHMs. Out of the two field analyzer, one (the AMS THM100™) was an online analyzer, whereas the other one (Parker) was used for grab sample analyses. While direct comparison between different field analyzers, and comparison of field analyzers with laboratory results were not an explicit objective of this project, duplicate samples were collected and analyzed through different laboratory and field instruments on a daily basis to ensure that erroneous results are not received.

Figure 4-23 shows a comparison between TTHM concentration results obtained from the AMS THM100™ instrument and the laboratory analyses for a period of 4 days between November 24 and 27, 2014. As can be seen from the figure, there is an excellent correlation between the AMS instrument data and laboratory results. Throughout the duration of the testing, the AMS instrument results matched laboratory results within ± 10%. In addition to the TTHM concentrations, the individual THM species concentrations also matched very well between the AMS instrument and the laboratory.

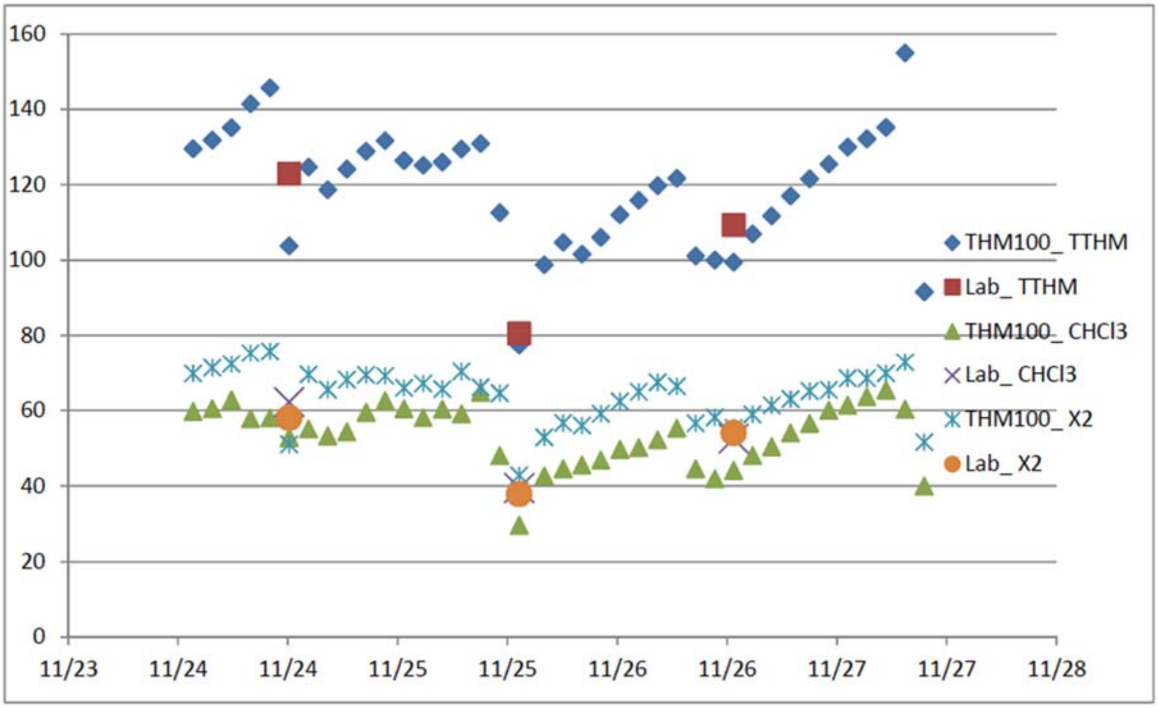


Figure 4-23 Comparison of TTHM concentration results obtained from AMS THM100™ and laboratory analyses

Figure 4-24 shows a comparison between TTHM concentration results obtained from the Parker TTHM analyzer and the laboratory analyses for a few days between December 9 and 23, 2014. Similar to the AMS instrument, the Parker analyzer also showed a very good correlation with laboratory analyses. There were a couple of sampling and preservation steps needed as part of the grab sample analyses with the Parker analyzer. These included quenching of chlorine in the collected samples, and holding the samples in a headspace-free container until the water temperature equilibrated to room temperature. That said, the TTHM concentrations obtained from the Parker analyzer were for the most part within ± 20% of the laboratory results throughout the 2 month demonstration testing period.

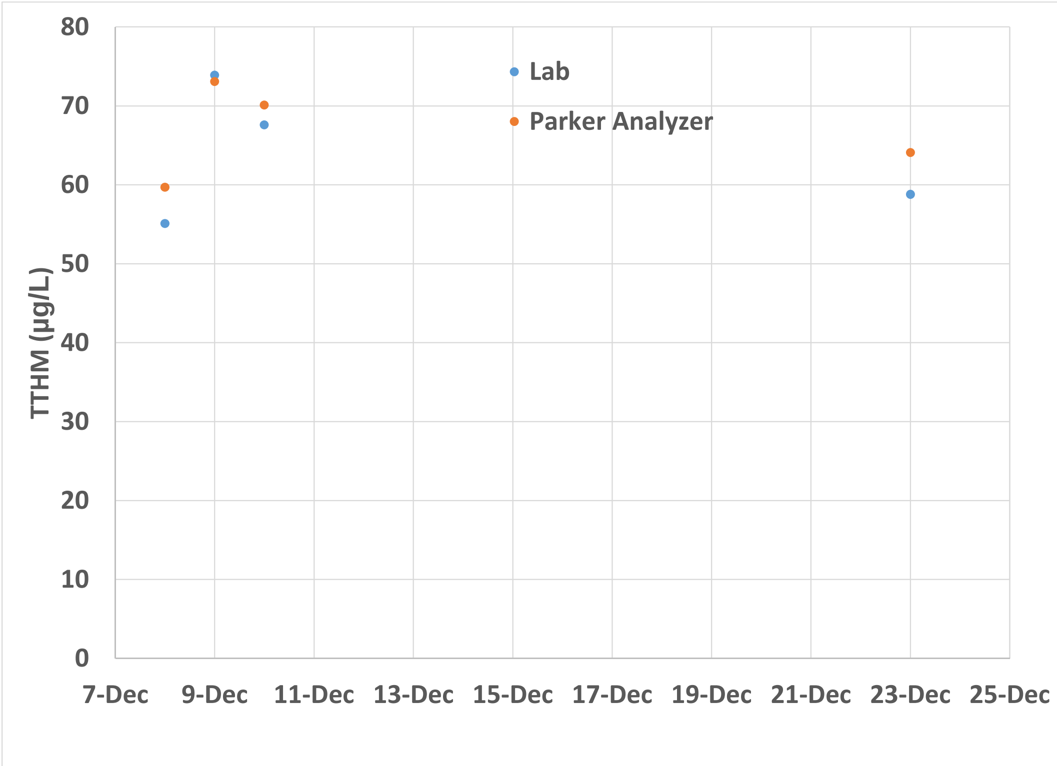


Figure 4-24 Comparison of TTHM concentration results obtained from Parker TTHM analyzer and laboratory analyses

HAA5 and TOX Results

While the focus of this project was TTHM removal via aeration technologies, limited sampling and analyses were also performed to determine other DBP concentrations that were formed through the process. The other DBPs analyzed as part of this project were the HAA5s and total organic halides (TOXs).

Table 4-5 HAA5 concentrations in WTP effluent and clearwell effluent

HAA Species	WTP Effluent	Clearwell Effluent
Monochloroacetic acid (µg/L)	0	0
Dichloroacetic acid (µg/L)	10.3	16.8
Trichloroacetic acid (µg/L)	10.5	20.1
Monobromoacetic acid (µg/L)	1.8	3.1
Dibromoacetic acid (µg/L)	2.8	4.8
Bromochloroacetic acid (µg/L)	6	11.2
Total HAA5 (µg/L)	25.2	44.8

Table 4-5 shows the HAA5 concentrations in the WTP effluent and in the clearwell effluent during the demonstration testing period. As seen in the table, there is a significant increase in the HAA5 concentrations between the WTP effluent and the clearwell effluent indicating HAA5 formation within the clearwell. However, even the clearwell effluent HAA5 concentration of 44.8 µg/L is significantly lower than the HAA5 MCL of 60 µg/L. Trichloroacetic acid is the most dominant HAA5 species followed by dichloroacetic acid. Note that bromochloroacetic acid, although shown in Table 4-5, is not a regulated HAA, and its concentration is not part of the total HAA5 concentrations shown in the table.

Table 4-6 shows the TOX concentrations, and corresponding TTHM and HAA5 concentrations in the WTP effluent, and clearwell effluent under baseline conditions and spray aeration testing. As can be seen from the table, there is no significant difference between the TOX concentrations in the WTP effluent and in the clearwell effluent during baseline and spray aeration testing. Given that the WTP effluent TOX concentrations are more than 90% of clearwell effluent TOX concentrations, it can be inferred that TOXs are formed pretty quickly in the water upon application of chlorine.

Secondly, comparing the clearwell effluent TOX concentrations between the baseline and spray aeration conditions, it appears that not much TOX is removed by aeration. It may so happen that when TTHMs are removed by aeration, other TOX species are formed such that the overall TOX concentrations are not reduced significantly. Paired TTHM and HAA5 samples were not collected with the TOX samples under all conditions, but the results of the clearwell effluent during spray aeration testing shows that TTHMs comprise approximately 37% of TOXs on a mass basis, while HAA5s comprise 19.6% of TOXs on a mass basis. It is likely that other organic halides make up the remainder of the TOX concentrations observed in these results.

Table 4-6 TOX, TTHM, and HAA5 concentrations in WTP effluent and clearwell effluent during baseline testing and spray aeration testing

Parameter	WTP Effluent	Clearwell Effluent – Baseline Conditions	Clearwell Effluent – Spray Aeration
TOX (µg/L)	230	250	240
TTHM (µg/L)			89.3
HAA5 (µg/L)			47.2

CHAPTER 5
CONCLUSIONS AND RECOMMENDATIONS FOR BEST PRACTICES

This project was the first of its kind in testing TTHM removal effectiveness of spray aeration, surface aeration, mixer, and ventilation technologies side by side in the same clearwell under the same water quality conditions. The demonstration testing yielded a significant amount of new data and insights into the different physical and chemical processes that need to be considered during selection of aeration technologies for TTHM removal. However, the demonstration testing also highlighted some limitations of implementing aeration technologies into WTP clearwells, and seasonal (temperature) and WTP operational impacts on the effectiveness of aeration technologies for TTHM removal. The following section summarizes the conclusions that were drawn from the two month demonstration testing

CONCLUSIONS FROM DEMONSTRATION TESTING

The demonstration testing of the aeration technologies yields the following summary conclusions:

- Both surface and spray aeration systems were estimated to achieve between 19 and 34 percent TTHM removal in the OMT WTP clearwell. The removal of TTHMs were lower than the 50 – 60 percent TTHM removal that was predicted from these aeration systems during the development of the EDR. The difference in TTHM removal efficiencies was primarily due to the lower water temperatures (as low as 6°C) experienced during demonstration testing compared to the water temperatures (greater than 15°C) anticipated during development of the EDR.
- It is important to distinguish between TTHM removal by aeration technologies and overall TTHM reduction through the clearwell. The overall TTHM reduction through the clearwell is influenced by multiple factors including variation of hydraulic residence times in the clearwell, formation of TTHMs within the clearwell, and dilution of aeration treated water with fresh water pumped by the WTP. As such, the overall TTHM reduction through the clearwell was lower than the TTHM removal by the aeration systems. From a broader perspective, clearwell aeration is most successful when the clearwell has a really long hydraulic residence time, or if the DBPs in a specific water are really fast forming. In the case of the OMT WTP, neither of these conditions occurred.
- Between the surface aeration and the spray aeration systems, the TTHM removal efficiency of the spray aeration system was marginally better. In a clearwell of this size and geometry, typically a spray aeration system is anticipated to perform better than a surface aeration system, because there is limited surface area available for the surface aeration to be effective. Additionally, in this particular case, the design and installation of the surface aeration system was not optimal as it was a temporary installation. The surface aerator was not positioned in the center of the clearwell, and the nearest clearwell wall was approximately 4 feet away from the surface aerator. This did not allow optimal air: water transfer of TTHMs which contributed to the diminished performance of the surface aerator.
- For both the surface aeration and spray aeration systems, TTHM removal efficiencies improved with the active ventilation. In general, TTHM removal efficiencies were 2 to 4

percent higher with active ventilation compared to passive ventilation for both surface and spray aeration systems.

- The mixer and the ventilation system by themselves did not show appreciable TTHM removal. The observed lower TTHM concentrations during mixer and ventilation testing compared to the baseline testing were likely due to lower water temperatures. Given the WTP and high service pumps operation, this clearwell is very well exercised, being filled and drained two to three times per day. As such, the clearwell is already pretty well mixed, and so the mixer was not expected to improve performance significantly. The ventilation fan assisted with TTHM removal when the spray or the surface aeration system were switched on, but the ventilation system alone was not expected to show significant TTHM removal performance.
- The most important lesson learned through the demonstration testing is that for the OMT WTP clearwell, the hydraulic residence time is the primary controlling parameter in determining overall TTHM reduction. During the daytime hours, when both the WTP and the high service pumps were operational either continuously or intermittently, the average hydraulic residence time within the clearwell could be as low as 2 hours, and within that time no TTHM reduction was observed. Conversely, when there was no water flowing in or out of the clearwell during overnight hours, the clearwell behaved like a batch reactor, and higher TTHM reduction was observed.
- From the demonstration testing results it is evident that implementation of aeration technologies within the OMT WTP clearwell will not be sufficient to lower distribution system TTHM concentrations below MCL levels. While aeration technologies can assist in TTHM reduction, other process improvements within the WTP, such as organics removal, will be necessary to manage distribution system TTHM concentrations.
- One of the important considerations during the design and implementation of aeration systems in WTP clearwells is CT impacts. Any aeration system is likely to mix the water in the reservoir such that the baffling factor will be reduced. If CT credits are being claimed through the reservoir, it is important to take the reduction of baffling factor into consideration, and ensuring that sufficient CT is still achieved with the aeration system in place.
- Evaluation of the field TTHM analytical instruments demonstrated that these instruments are easy to install and operate, can generate TTHM results quickly, and most importantly accurate and precise. Throughout the duration of the demonstration testing, results obtained from the AMS THM100™ analyzer were within ± 10% of laboratory results. Similarly, results obtained from the Parker THM analyzer were within ± 20% of laboratory results during the demonstration testing period.

RECOMMENDATIONS FOR BEST PRACTICES FOR AERATION TECHNOLOGY SELECTION AND IMPLEMENTATION

Aeration technologies have become increasingly popular in recent times for the mitigation of high TTHMs in the distribution system due to a number of factors – aeration technologies are less capital intensive to implement than other DBP precursor removal technologies, easy to operate and maintain, do not require any footprint for installation, and do not generate any residuals. While aeration technologies can be a very cost-effective treatment alternative for high TTHM mitigation, they are not appropriate for application in all high TTHM situations. Secondly, even if aeration technologies were appropriate for a particular scenario, additional evaluations are necessary to determine the most appropriate type and design of aeration system that should be selected and implemented. A step-by-step process needs to be adopted for determination of appropriateness of aeration technologies, and selection of the suitable aeration type and design. The key factors in the evaluation of aeration technologies include:

- Understanding the extent of the DBP problem
- Evaluation of the treatment site, including the reservoir design
- Selection of the appropriate aeration technology
- Design of the aeration technology

These factors are discussed briefly in the following sections.

Understanding the Extent of the DBP Problem

Prior to evaluation of any treatment technology or management option, the extent of the DBP problem needs to be understood. In order to do this, analysis of historical DBP data is necessary along with WTP operational data. Historical DBP data should be analyzed to determine the TTHM LRAAs at the Stage 2 DBPR compliance sites or other locations of interest. Secondly, TTHM reformation post removal also needs to be accounted for. For example, aeration technologies remove pre-formed TTHMs from the water, but they do not alter TTHM formation potential of the water. So, if there is additional organics and chlorine left in the post-aerated water, TTHM reformation will continue at the same rate as pre-aerated water. Thirdly, aeration technologies only remove TTHMs, but not HAA5s, because they are not volatile. If the Stage 2 DBPR sampling locations exceed both TTHM and HAA5 MCL levels, application of an aeration technology will not mitigate the HAA5 compliance concern.

Once the historical TTHM data have been evaluated, the next step is to determine if an aeration technology is feasible in mitigating the issue. Aeration technologies can only be installed in WTP clearwells or distribution system reservoirs. So the relationship between the location of the clearwell/ reservoir and the Stage 2 DBPR sampling sites in terms of water age and TTHM reformation needs to be established. This sets some practical limitations on both the highest TTHM concentrations where mitigation by aeration is feasible, and locations where aeration technology can be implemented. This is better explained graphically.

Figure 5-1 presents a conceptual graph of a water utility that may have an elevated TTHM compliance issue. Assume that the x-axis represents all the sampling locations in the utility's distribution system starting with the WTP at the extreme left and the Stage 2 DBPR monitoring location with the maximum hydraulic residence time at the extreme right. The sampling sites A, B, C, etc. are arranged by increasing TTHM concentrations. The y-axis represents TTHM concentrations. The green curve represents the TTHM concentrations at the various sampling locations.

For the sake of simplicity, assume that TTHM concentrations in all four quarters of the year are identical, and as such individual TTHM concentrations are equal to the LRAA value. Also assume that the TTHM concentrations at the Stage 2 DBPR MRT site exceed TTHM MCL by X μg/L. Aeration can be implemented at any location at the WTP or in the distribution system. However, knowing that TTHM reformation occurs at the same rate in post-aerated water as in pre-aerated water (refer to Figure 1-2 in Chapter 1), wherever aeration technologies are implemented a mass removal of X µg/L of TTHMs is required such that all distribution system sampling locations have TTHM concentrations lower than the TTHM MCL.

In the best case scenario, aeration technologies can remove 100% of the pre-formed TTHMs. More realistically, aeration systems are designed such that they remove at least 50% of the pre-formed TTHMs. With this in mind, aeration technologies can only be implemented in the area between sampling site A and sampling site C in the distribution system. In the figure, all sampling sites to the left of site A have TTHM concentrations lower than X µg/L. So if aeration technologies are implemented at sites to the left of site A, even if 100% of TTHMs are removed, TTHMs will reform post aeration, and by the time the water reaches the Stage 2 DBPR MRT site, TTHM concentrations will be higher than the TTHM MCL.

Similarly, in the figure, TTHM concentrations are at their MCL value at site C. As such, implementation of aeration technologies at any site to the right of site C will leave any site between site C and the selected site out of Stage 2 DBPR compliance. In order for the utility to be in Stage 2 DBPR compliance, the aeration technology implementation site has to be somewhere between site A and site C. This is shown by the area inside the box in Figure 5-1.

Now, within the area of the box, aeration can be implemented at any site, such as site A, B, or C. However, as aeration occurs through transfer of TTHMs from the aqueous to the gaseous phase, higher the TTHM concentration in the aqueous phase, more the mass transfer. As such, in order to achieve the same mass removal of TTHMs, the aeration system designed for site A needs to be designed with higher power input than an aeration system for site B, which in turn needs to be designed with higher power input than an aeration system for site C. For example, the aeration system for site A needs to be designed such that in can remove 100% of TTHMs, whereas at site C, the aeration system needs to be designed such that it only removes a small fraction of the pre-formed TTHMs. Based on this figure, it is evident that if all other site conditions are similar, the best site for aeration system implementation for TTHM control for this utility is site C.

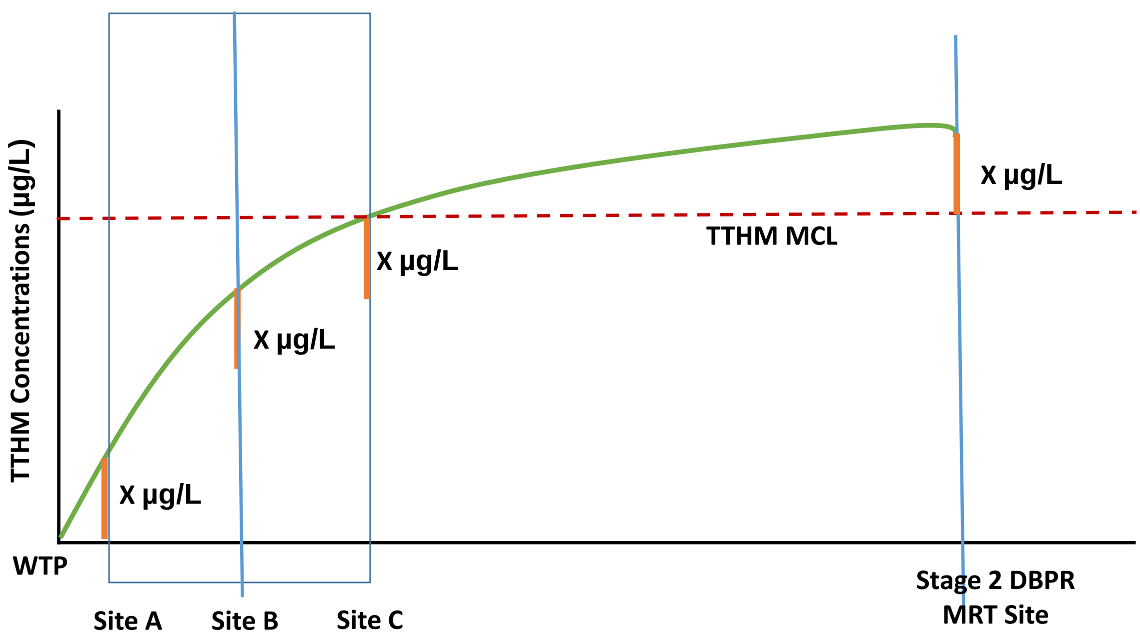


Figure 5-1 Analyses of TTHM data to determine appropriate aeration technology application locations

The other insight that can be gained from Figure 5-1 is the maximum theoretical value of X. Given that site C is the best location for aeration system installation, the best designed aeration system can remove 100% of the pre-formed TTHMs. At site C, that is equal to the TTHM MCL of 80 µg/L. So, the maximum theoretical value for X is 80 µg/L. This translates to TTHM concentrations of 160 µg/L at the Stage 2 DBPR MRT location. In other words, aeration technology, by itself, can only assist utilities for whom the TTHM LRAA concentrations at their Stage 2 DBPR MRT sites are less than or equal to 160 µg/L (and possibly lower to account for a factor of safety). For utilities that have higher TTHM LRAA concentrations, single-stage aeration by itself will not be able to bring them to Stage 2 DBPR compliance and either multiple-stage aeration systems, or additional process or operational improvements will be necessary.

In a more realistic case, where aeration technologies can only remove 50% of pre-formed TTHMs, the value of X is 40 µg/L. This translates to TTHM concentrations of 120 µg/L at the Stage 2 DBPR MRT location. Utilities that have TTHM LRAA concentrations higher than 120 µg/L will require additional process or operational improvements beyond implementation of aeration technologies to be in Stage 2 DBPR compliance.

Evaluation of the Treatment Site Including the Reservoir Design

Once historical TTHM data have been analyzed and it has been determined that aeration is a feasible treatment alternative for the mitigation of elevated TTHM concentrations, then the treatment site and clearwell/ reservoir need to be evaluated such that the appropriate aeration system can be selected. The following design parameters of the clearwell/ reservoir have significant influence on the aeration system selection:

- Reservoir capacity
- Reservoir geometry
- Inlet pipe and outlet pipe configuration
- Reservoir access hatch location, size, and geometry
- Baffles inside the reservoir
- Any other structures or equipment inside the reservoir
- Whether disinfection credits are being claimed through the reservoir (particularly relevant if the reservoir is a clearwell at the WTP)

The significance of each of these parameters are not discussed here, but each of these may drive the selection of the most appropriate aeration system. A site specific evaluation would be necessary.

Aside from the reservoir, other treatment site related factors that may influence the selection and design of the aeration system include:

- Availability of adequate electrical supply on site
- Local air quality regulations that may limit the maximum mass of volatile compounds that can be released into the atmosphere
- Coordination with local regulatory agency that will be involved in permitting of the aeration system

The evaluation of these treatment site and reservoir design conditions will help in identifying the different aeration alternatives that can be implemented within the reservoir.

Selection of the Appropriate Aeration Technology

Both surface and spray aeration systems achieve the objective of TTHM removal from water by transfer of TTHMs from the aqueous phase to the gaseous phase. However, the design and operation of the two systems are very different from one another. Both surface aeration and spray aeration systems have some unique advantages and disadvantages, and as such one can be more favorable than the other in a given application scenario. The differences between surface and spray aeration systems are briefly summarized below:

- The capital cost of a surface aerator can be higher than that of a spray aeration system. This is especially true for a small sized reservoir, where the cost of implementation of a small spray aeration system is very low.
- On the other hand, operational and maintenance (O&M) costs for a surface aeration system can be lower than that of a spray aeration system. A significant fraction of annual operating costs of an aeration system is electrical power costs. For the removal of the same mass of TTHMs, surface aerators require less power than spray aeration systems, and as such annual O&M costs of a surface aeration system can be lower than that of a spray aeration system
- Installation of a surface aerator requires two mooring posts that guide the vertical movement of the surface aerator when the water level changes in the reservoir. For reservoirs where installation of mooring posts are not possible, spray aeration system may be a more favorable option
- Installation of a spray aeration system involves a spray pump and pipe. Depending on the site constraints and hydraulic conditions, the spray pump and pipe can be located either inside or outside the reservoir.
- Based on reservoir size and geometry and cost of implementation, spray aeration systems are generally more favorable in smaller reservoirs (0.2 MG or lower capacity). Conversely, surface aerators are more favorable in larger reservoirs (1 MG or higher capacity). For reservoirs between 0.2 MG and 1 MG in capacity, either of the two types of aeration systems may perform better. In this case, a site specific evaluation needs to be performed to determine the most appropriate aeration system.

Table 5-1 summarizes the different types of clearwells and distribution system reservoirs in terms of capacity and geometry, and indicates whether spray or surface aeration may be more suitable for implementation at those reservoir sites. There are certain types of reservoirs, such as very large standpipes or spheroids where neither spray nor surface aeration may be suitable for TTHM concentration reduction. It needs to be emphasized that the favorability of spray or surface aeration systems as shown in Table 5-1 are only suggested based on previous experience (Seidel et al. 2010) at similar reservoirs, however, a site-specific evaluation needs to be conducted to determine the appropriate aeration technology at a given reservoir site.

Table 5-1 Suitable aeration systems for different reservoir capacities and geometry

Reservoir Capacity	**0.01 MG**	**0.1 MG**	**1 MG**	**10 MG**
Clearwell				
Steel on grade	X	X	X, Y	Y
Concrete on grade	X	X	X, Y	Y
Concrete below grade	X	X	X, Y	Y
Distribution system reservoir				
Standpipes	X	X	X	NA
Spheroids	X	X	X	NA
Steel on grade	X	X	X, Y	Y
Concrete on grade	X	X	X, Y	Y

X – Spray aeration likely more suitable
Y – Surface aeration likely more suitable
NA – Neither spray nor surface aeration are suitable

Design of the Aeration Technology

Once an aeration system is selected, it needs to be designed appropriately for the particular reservoir site. Key considerations involved in the design of a spray aeration system and a surface aeration system are summarized below. Once designed, several operational issues such as process control and water quality testing (e.g. pre- and post- aeration chlorine levels, pre- and post- aeration DBP levels, post-aeration TOC levels, etc.) will need to be considered and updated due to the installation of the aeration system.

For the design of a spray aeration system, the following items need to be considered:

- Spray pump capacity
- Flow rate and operating pressure
- Spray pump location (submerged versus outside the clearwell)
- Spray piping design and layout
- Nozzle type and size of droplets
- Number of nozzles
- Electrical supply and connections
- Ventilation system design
- Maintenance access

For the design of a surface aeration system, the following items need to be considered:

- Surface aerator capacity
- Float design for through-hatch installation
- Mooring post design and installation
- Electrical supply and connections
- Ventilation system design
- Maintenance access

Additionally, the following tank modifications need to be considered:

- Larger capacity vent for air exchange on tank roof
- Additional air exchange outlets on tank roof
- Additional construction of tank hatch entries for equipment
- Power supply to tank
- Maintenance access
- Possible piercings through tank wall

REFERENCES

APHA (American Public Health Association), AWWA (American Water Works Association), and WEF (Water Environment Federation). 2005. *Standard Methods for the Examination of Water and Wastewater*. 21st ed. Washington, D.C.: APHA.

AWWA (American Water Works Association). 2011a. *Water Quality and Treatment: A Handbook on Drinking Water*. 6th ed. Denver, Colo.: AWWA.

AWWA (American Water Works Association). 2011b. *Disinfection of Water Storage Facilities*. AWWA C652-11. Denver, Colo.: AWWA.

Brooke, E., and M.R. Collins. 2011. "Posttreatment Aeration to Reduce THMs." *Jour. AWWA* 103(10): 84-96.

Clark, T.F. 2013. "THM Removal: Small System Application." Presentation at the Finger Lakes Conference, Watkins Glen, New York.

Edzwald, J.K., and J.E. Tobiason. 1999. "Enhanced Coagulation: USA Requirements and a Broader View." *Water Science and Technology* 40(9): 63-70.

EPA (U.S. Environmental Protection Agency). 1988. *In-House Pilot Studies for Control of Chlorination By-Products*, Organics Control Branch, Drinking Water Research Division, Risk Reduction Engineering Laboratory. Cincinnati, Ohio.

EPA (U.S. Environmental Protection Agency). 1994. *Water Treatment Plant Model for MS Windows 3.1: Version 1.55*.

EPA (U.S. Environmental Protection Agency). 2007. Complying with Stage 2 Disinfectants and Disinfection By-products Rule: Small Entity Compliance Guide. Accessed January 1, 2015. http://www.epa.gov/ogwdw/disinfection/stage2/pdfs/guide_st2_stepguide_smallentitycomplianceguide.pdf

EPA (U.S. Environmental Protection Agency). 2014. Safe Drinking Water Information System. Accessed May 1, 2014. http://www.epa.gov/enviro/facts/sdwis/search.html

Fiske, P.S., J. Oppenheimer., R. Moore. and R. Everett. 2011. "In-Tank Aeration Predicts and Reduces THMs." *AWWA Opflow*, November 2011: 22-24.

Hirschhorn, E.A., and R. Moore. 2014. "Reduction of THMs within Storage Tanks Using Aeration." Presentation at the Pacific Northwest Section AWWA 2014 Annual Conference, Eugene, OR, May 9, 2014.

Jacobsen, L., M. Fang. and D. Machado. 2011. "Aeration System Addition and Operation for Distribution System Trihalomethane Control." Presentation at the AWWA Annual Conference, Washington D.C., June 12 – 16, 2011.

Michigan Technological University. 1999. *Aeration System Analysis Program, ASAP™*.

Reid, L.W. 2012. "Localized Treatment Solutions for TTHM Management." Presentation at the New York Section AWWA Annual Water Event & Expo, April 17 – 19, 2012. New York.

Roberts, P.V., and J.A. Levy. 1985. "Energy Requirements for Air Stripping Trihalomethanes." *Jour. AWWA* 77(4): 138-146.

Schneider, O.D., M.W. LeChevallier, J. Yang, D.M. Hughes, and H. Reed. [N.d]. *Localized Control of Disinfection By-Products By Spray Aeration in Storage Tanks*. Denver, Colo.: Water Research Foundation. Forthcoming.

Seidel, C.J., S. Acquafredda. J.M. Jensen, and G. Tang. 2010. "Aeration Strategies for Total Trihalomethanes (TTHMs) Control" Presentation at the AWWA Annual Conference, June 20-24, Chicago, IL.

Sherant, S.R. 2008. "Trihalomethane Control by Aeration." Master's thesis, The Pensylvania State University.

Staudinger, J., and P.V. Roberts. 1996. "A Critical Review of Henry's Constant for Environmental Applications." *Critical Reviews in Environmental Science and Technology*, 26(3): 205-297.

Weishaar, J.L., G.R. Aiken. B.A. Bergamaschi, M.S. Fram., R. Fujii, and K. Mopper. 2003. "Evaluation of Specific Ultraviolet Absorbance as an Indicator of the Chemical Composition and Reactivity of Dissolved Organic Carbon." *Environ. Sci. Technol.,* 37: 4702-4708.

ABBREVIATIONS

ACDE	Association of Commercial Diving Educators
AMS	Aqua Metrology Systems
ASAP	Aeration System Analysis Program
A/W	Air: Water
AWWA	American Water Works Association
^{o}C	Degree Celcius
CCPP	Calcium carbonate precipitation potential
CPR	Cardiopulmonary resuscitation
DBCM	Dibromochloromethane
DBP	Disinfection Byproduct
DBPR	Disinfectants and Disinfection Byproduct Rule
DOC	Dissolved organic carbon
EC	Enhanced coagulation
EDR	Engineering Design Report
EPA	Environmental Protection Agency
GAC	Granular activated carbon
GC	Gas chromatography
HAA	Haloacetic acid
HAA5	Five regulated haloacetic acids
IPCC	Intergovernmental Panel on Climate Change
LRAA	Locational running annual average
LSI	Langelier Saturation Index
MCL	Maximum Contaminant Level
MCLG	Maximum Contaminant Level Goal
MCWA	Monroe County Water Authority
MERV	Minimum efficiency reporting value
MRT	Maximum residence time
NELAC	National Environmental Laboratory Accreditation Conference
NSF	NSF International
ODEQ	Oklahoma Department of Environmental Quality
O&M	Operation & maintenance
OMT	OTOE-Missouria Tribe
ORD	Office of Research and Development

OSHA	Occupational Safety and Health Administration
PVC	Polyvinyl chloride
SDWIS	Safe Drinking Water Information System
SUVA	Specific ultraviolet absorbance
TNI	The NELAC Institute
TOC	Total organic carbon
TOX	Total organic halide
TTHM	Total trihalomethane
USB	Universal serial bus
UV	Ultra violet
UV_{254}	Ultraviolet absorbance at 254 nm
VAC	Volt AC
VOC	Volatile organic compound
W.C.	Water column
WRF	Water Research Foundation
WTP	Water treatment plant

APPENDIX A

Reducing Volatile Disinfection Byproducts in Treated Drinking Water Using Aeration

OTOE-Missouria Tribe TTHM Mitigation Design Report

Prepared by: Jacobs Engineering Group, American Water, and Corona Environmental Consulting

August 15, 2014

REGISTERED PROFESSIONAL ENGINEER
DOUGLAS LEE SMITH
18145
OKLAHOMA

Douglas L. Smith
8-15-2014

JACOBS

777 Main Street
Fort Worth, Texas 76102 USA
817.735.6000 Fax 817.735.6148

August 15, 2014

Mr. Rocky Chen
Oklahoma Department of Environmental Quality
Water Quality Division
707 North Robinson
Oklahoma City, OK 73101-1677

Re: OTOE-Missouria Tribe Aeration Testing Project Funded by USEPA
PWSID No. OK1021222

Dear Mr Chen:

The United States Environmental Protection Agency (USEPA) has funded this project to test aeration systems for TTHM reduction. The utility selected for this project is the OTOE-Missouria Tribe water treatment plant (WTP) clearwell located near Red Rock, Oklahoma. A draft version of the attached report was submitted to you electronically on June 28, 2014. Your comments were received, addressed, and incorporated in this revised report. This revised version includes basis for design and drawings for aeration equipment installation and the protocol of operations during the pilot testing period. This report also includes a letter from OTOE-Missouria Tribe indicating their endorsement of this project.

As part of this submission packet, we are also including the Application for Permit to make temporary modifications to the OTOE-Missouria Tribe WTP treatment processes, and a corresponding application fee.

If you have any questions on the plans for aeration equipment installation and testing please contact me by phone at (817) 735-6000 or by email at doug.l.smith@jacobs.com. Alternatively, Rich Grass with the OTOE-Missouria Tribe can be contacted by phone at (580) 723-4372 or by email at rgrass@omtribe.org.

Very truly yours,

JACOBS ENGINEERING GROUP INC.

Douglas L. Smith

Doug L. Smith, P.E.
Manager of Projects

File WVXX8100/600

OTOE·MISSOURIA
TRIBE OF INDIANS

8151 HIGHWAY 177
RED ROCK, OK 74651-0348

July 25, 2014

Mr. Rocky Chen
Oklahoma Department of Environmental Quality
Water Quality Division
707 North Robinson
Oklahoma City, OK 73101-1677

Re: OTOE-Missouria Tribe Aeration Testing Project Funded by USEPA
PWSID No. OK1021222

Dear Mr. Chen,

The OTOE-Missouria Tribe is pleased to participate in the United States Environmental Protection Agency (USEPA) funded project to test aeration systems for TTHM reduction. Our utility has had challenges in the past with high TTHM concentrations in our distribution system, and the clearwell at our water treatment plant is an appropriate location for testing the aeration technologies.

We have reviewed the engineering report developed by the team of Jacobs Engineering Group, Corona Environmental Consulting, and American Water, and agree with the testing approach outlined in the report. We will be able to operate our water treatment plant and the clearwell in the manner outlined in the report during the testing period, such that data for the project can be collected seamlessly without any interruptions to our water production.

If you have any questions or comments, please do not hesitate to contact me by phone at (580)-723-4372, or by email at rgrass@omtribe.org

Very truly yours,

OTOE-Missouria Tribe

Richmond W. Grass

Rich Grass

Title: Water Plant Director

Organization: Otoe-Missouria TRIBE

Mailing Address: 8151 Highway 177
Red Rock, OK 74651

PHONE: 580.723.4466 • TOLL FREE: 877.692.6863 • FAX: 580.723.4273 • www.omtribe.org

Table of Contents

List of Tables

List of Figures

List of Appendices

1.0 Background

The Water Research Foundation (WRF), United States Environmental Protection Agency (USEPA), and OTOE-Missouria Tribe (OMT), together with consulting firms of Jacobs Engineering Group, Corona Environmental Consulting, and American Water are participating in this project that evaluates aeration alternatives to reduce total trihalomethanes (TTHMs) in the OMT distribution system. Under the Stage 2 DBP Rule there are two classes of regulated DBPs, TTHMs and five haloacetic acids (HAA5s) with maximum contaminant levels (MCL) of 80 µg/L and 60 µg/L, respectively. The Stage 2 Rule requires sampling throughout the distribution system and compliance is based on a locational running annual average (LRAA). Sampling conducted by OMT indicates Stage 2 sampling locations in their distribution system are challenged to achieve compliance.

The OMT water treatment plant (WTP) serves a population of approximately 250 and is supplied by raw water via a pipeline from Kaw Lake and Stillwater, OK. The OMT WTP process consists of twin Microfloc® Trimite™ 50 units (Adsorption Clarifier and Mixed Media Filter), with a coagulant/polymer blend and sodium hypochlorite disinfection prior to entering a 20,000 gallon clearwell for storage and disinfection contact time. Treated water is pumped from the clearwell to the OMT distribution system including 110,000 gallon standpipe near the WTP.

The objective of this project is testing of surface and spray aeration technologies to reduce TTHM concentrations in the OMT distribution system to levels that are compliant with the Stage 2 DBP Rule (< 80 µg/L LRAA).

This report describes the evaluation of spray and surface aeration for TTHM reduction and design basis for these strategies at the clearwell. This report includes the following sections:

- Historical WTP operation and water quality parameters;
- Description and design basis for the aeration technologies;
- Pilot testing protocol including water quality monitoring and system operations approach.

2.0 Site Description

The WTP and clearwell are located in the vicinity of the intersection of Windmill and Highway 177, near the town of Red Rock, Oklahoma as shown in Figure 1.

Figure 1 OMT WTP Site Plan

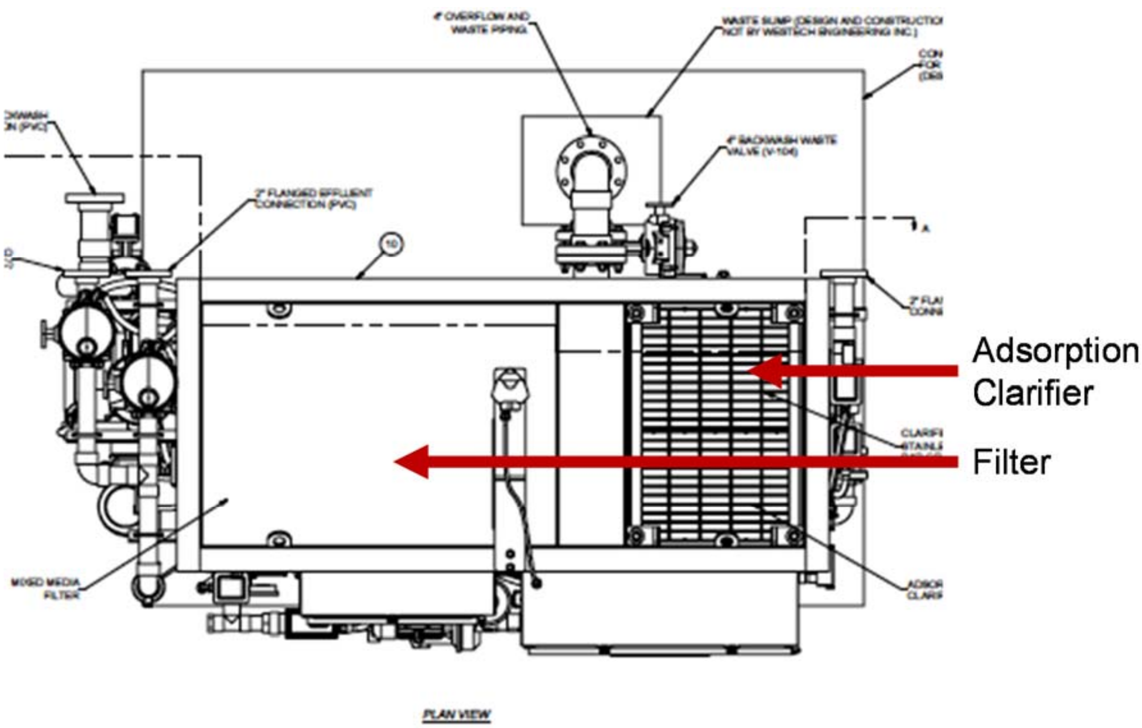
The WTP operates as needed to maintain storage in the nearby 110,000 gallon standpipe. The WTP site includes the following existing infrastructure.

- Site Building including:
  - Twin Microfloc® Trimite™ 50 units (Adsorption Clarifier and Mixed Media Filter)
  - Coagulant/polymer blend and feed system
  - Sodium hypochlorite disinfection feed system
  - Office and laboratory
- 20,000 gallon steel welded clearwell (12 foot diameter, 24 foot height)
- Two booster pumps with a combined capacity of 80 gpm;
- Valves, piping, and associated appurtenances
- Twin backwash ponds

Microfloc® Trimite™ 50 Units Design

The OMT WTP has two Microfloc® Trimite™ 50 two stage package treatment units. The first stage is an Adsorption Clarifier designed for turbidity removal, followed by the second stage that is a Mixed Media Filter. Each of the two package units has a design capacity of 50 gpm. Figure 2 shows a schematic of the package treatment unit.

Figure 2 Schematic of the Microfloc® Trimite™ 50 Package Treatment Unit



As can be seen from the schematic, there are several pieces of equipment and media within both the Adsorption Clarifier chamber and the Mixed Media Filter chamber. It is difficult to calculate the exact "effective volume" of water within each chamber. However, for the purpose of getting disinfection credits upon prechlorination through the package treatment units, an estimate of the effective volumes of the Adsorption Clarifier chamber and Mixed Media Filter chamber were developed. These calculations are shown in Table 2-1. Based on these volumes, disinfection credits were calculated as shown in Table 2-2.

Table 2-1 Estimated effective volumes of Adsorption Clarifier chamber and Mixed Media Filter chamber of the Microfloc® Trimite™ 50 package treatment plant

Adsorption Clarifier Dimensions	23 in (L) X 31.5 in (W) X 47 in (H)
Adsorption Clarifier Volume	147.4 gal
Mixed Media Filter Dimensions	46 in (L) X 31.5 in (W) X 45.5 in (H)
Mixed Media Filter Volume	285.4 gal
Total Volume: Clarifier + Filter	432.8 gal
Total Volume of 2 Trimite™ Units	865.6 gal

Clearwell Operations

The OMT WTP clearwell is typically operated at levels between 8 and 22 feet, which correspond to tank volumes of approximately 6,800 and 18,600 gallons, respectively. The height of the clearwell inlet riser pipe is 8 feet. There is a digital readout that indicates water level in the clearwell. Daily influent flow rates are typically less than 80 gpm, when the booster pumps are operating to direct flow from the Microfloc® units to the clearwell. The operation time of the microfloc units varies to keep pace with the distribution system demand.

Disinfection

The OTM WTP operations staff targets chlorine residual greater than 0.2 mg/L in the distribution system. Operations staff adjusts the chlorine residual leaving the WTP to achieve this distribution system target. Due to a combination of high temperatures and residual demand, the chlorine residual decreases as water moves through the distribution system.

During the testing of the aeration equipment, the point of chlorine application will be moved upstream of the package treatment units. Prechlorination in the raw water will be the only point of chlorine addition during the period of testing of the aeration technologies. As indicated in Table 2-2, a chlorine residual of 3.5 mg/L will be maintained through the WTP and clearwell throughout the duration of the aeration technologies testing. The necessary disinfection of a minimum 1.0 log *Giardia* inactivation will be achieved through the package treatment units and the clearwell. Table 2-2 shows a summary of the disinfection parameters for the testing period.

Table 2-2 Summary of disinfection parameters for testing period

Parameter	Pre-Chlorination CT Through WTP	CT Through Clearwell
Effective Basin Size (gallons)	865.6	6,800
Baffling Factor (T10/T)	0.7	0.1
Disinfection Method	Chlorine	Chlorine
Peak Flow Rate (gpm)	80	80
Disinfectant Conc. (mg/L)	3.5	3.5
pH (s.u.)	8.1	8.1
Temperature (°C)	15.0	15.0
Contact Time T10 (minutes)	7.6	8.5
CT_{Calc}	26.51	29.75
$CT_{99.9}$ (Giardia)	162.78	162.78
Log Inactivation (G)	0.49	0.55
$CT_{99.9}$ (Viruses)	4	4
Log Inactivation (V)	26.51	29.75

The disinfection credit achieved from the clearwell and WTP combined totals 1.04 log inactivation for *Giardia*. During the testing period when aeration equipment is turned on, a log sheet including the CT parameters listed above will be completed hourly by staff onsite. Minimum cut-off values for certain parameters (clearwell level, pH, chlorine residual) in order to maintain the 1.0 log *Giardia* inactivation will be stipulated within the field log sheets. If monitoring indicates that those parameters are below the minimum stipulated values, aeration equipment will be turned off until the paramaters are back within acceptable range. Based on the field recorded values, actual log inactivation achieved will be calculated daily (at the end of the day) during the period of testing. As shown in Table 2-2, CT parameters will be collected both after the WTP and after the clearwell, and log inactivation will be calculated individually through the WTP and the clearwell.

TTHM Concentrations

Under the Stage 2 DBP Rule, compliance is based on the LRAA. The IDSE report indicates TTHM LRAA concentrations in the distribution system as high as 180 ug/L for the sampling location at 24500 Windmill Road. TTHM concentration measured near the WTP site on 4/22/2014 was 99 µg/L. Given the high TTHM concentrations OMT has observed in their distribution system, it is unlikely that aeration alone will achieve compliance. For the purpose of conducting this pilot testing, the largest aeration systems that can be fit into the existing clearwell have been identified and analysis tools have been used to estimate the TTHM reduction that can be achieved by these systems. To estimate TTHM reduction for surface aeration the Aeration System Analysis Program (ASAP) developed by Michigan Technological University has been used. Models developed through the Water Research Foundation Project No. 4413, Localized Control of DBPs by Spray Aeration in Storage Tanks, have been used for spray aeration performance estimates. The results from modeling TTHM reduction is summarized in Table 2-3.

Table 2-3 TTHM reduction modeling results

Parameter	Model Results		Comment
	Surface Aeration	Spray Aeration	
TTHM at Clearwell (ug/L)	100		Sample date 4/22/2014
TTHM leaving clearwell (µg/L)	40	50	Estimated by models for 2 hp surface aerator and 3 hp pump for spray aeration
TTHM Reduction at Clearwell	60%	50%	

3.0 Aeration Evaluation and Design

Since TTHMs are volatile, they can be removed with enhancing air / water contact through aeration. Aeration can remove TTHMs from water by enhancing a contact surface between air and water. The removal efficiency depends upon the volatility of the individual TTHM species related to the Henry's Constant, which increases with temperature. Higher Henry's constant results in higher species volatility. Table 3-1 presents Henry's Constant values for TTHM species at 20°C.

Table 3-1 Henry's Constant values (atm, 20°C) for TTHM species

THM Species	Formula	Henry's Constant (unitless)
Chloroform	$CHCl_3$	0.16
Bromodichloromethane	$CHCl_2Br$	0.085
Chlorodibromomethane	$CHClBr_2$	0.047
Bromoform	$CHBr_3$	0.025

Three aeration strategies were evaluated to reduce TTHMs in the OMT WTP clearwell, including two in-reservoir aeration strategies (spray aeration and surface aeration) and one external aeration strategy (hydrophobic membranes). Due to certain technical issues with the hydrophobic membranes (e.g. tolerance to high chlorine residual), and project constraints (schedule and budget), hydrophobic membranes will not be evaluated as part of the demonstration testing. The following subsections provide an overview of the spray aeration and surface aeration treatment technologies. It should be noted that aeration does not effectively remove HAA5s from water since they are much less volatile than TTHMs.

Spray Aeration

The spray aeration system includes an NSF 61 certified submersible pump, discharge pipe to direct flow to the reservoir ceiling, and spiral spray nozzle. Water in the reservoir will pass through the spray nozzle to form small droplets with high surface area that are sprayed into the reservoir. The design parameters that influence TTHM removal efficiency include the water droplet size and air-water contact time. For spray aeration the model for TTHM reduction was developed through the Water Research Foundation Project No. 4413, Localized Control of DBPs by Spray Aeration in Storage Tanks. The design assumptions used in the modeling are summarized in Table 3-2.

Table 3-2 Spray aeration modeling assumptions

Parameter	Value	Comment
Reservoir volume (gallons)	6,800	Minimum operating volume for test period
Minimum distance to water (ft)	2	Based on spray nozzle attached at a tank elevation of 24 feet
Influent flow rate (gpm)	80	Maximum operating flow for test period
Spray flow rate (gpm)	84	

For the spray aeration pumping flow rate of 84 gpm, it is estimated that 50% TTHM reduction will be achieved at the clearwell.

Surface Aeration

With this alternative, a floating surface aerator would be installed in the clearwell. The aerator would constantly draw in water from beneath the water surface, and spray it laterally through the air. For surface aeration installations in Phoenix, Arizona, the mixing has been investigated though monitoring and computational fluid dynamics modeling. These analyses suggest that near complete mixing is achieved with the use of a surface aerator. This mixing is accomplished by the aerator drawing water from below the surface and discharging it radially over the water surface. A 2 hp aerator draws water and discharges it at a rate of approximately 690 gpm with an impingement (white water) diameter of 7 feet.

TTHM reduction with surface aeration is proportional to the energy applied to the water in the reservoir. As indicated above, the model developed by Michigan Technological University, Aeration System Analysis Program (ASAP™)[1], was utilized to determine the TTHM removal that could be expected. The conditions that were evaluated using the ASAP™ model are shown in Table 3-3.

[1] ASAP™, 1999, D. Hokanson, D. Hand, J. Crittenden, Michigan Technological University, Houghton, MI.

Table 3-3 Surface aeration modeling assumptions

Parameter	Value	Comment
Reservoir volume (gallons)	6,800	Minimum operating volume for test period
Influent flow rate (gpm)	80	Maximum operating flow for test period
Power applied (hp)	2	

The model results suggest that a power input of 2 hp applied in the clearwell would achieve approximately 60% TTHM reduction.

The surface aerator selected for this application will be designed with a collapsible float. This float design allows for the aerator to be installed and maintained through the existing 24 inch square hatch. The surface aeration unit will be secured with posts to allow the unit to float in place as water levels change in the reservoir.

Tank Mixer

A tank mixer will be used during one phase of the demonstration testing – tank mixer and active ventilation. The objective of using the mixer is to ensure that the water in the tank is not stratified, and there is uniform water quality throughout the depth of the tank. A 120V tank mixer (Pax Water PWM 100) will be used for tank mixing.

Ventilation

Existing full scale aeration installations for TTHM reduction have demonstrated that best performance can be achieved with exhausting of air in the reservoir headspace and replacing it with outside, fresh air. This reservoir head space air exchange will be achieved through the use of a 120 volt air supply fan. The air flow rate is a function of the pressure loss that may happen over time, but even with a pressure loss of 0.75 in W.C., the air flow rate would be about 130 cfm (see fan cut sheet provided in Appendix B). Based on the project team's calculations, the minimum ventilation required for renewal of air in the tank head space is 100 cfm, so the selected fan should provide greater air flow than that. The ventilation fan will be used during the following phases of testing:

- Active ventilation
- Tank mixer and active ventilation

- Surface aerator with active ventilation
- Spray aeration system with active ventilation

The fan intake air will be filtered through #35, Type 316L stainless steel screen to prevent contaminant entry. A Camfil Multi Track 25 Filter Housing and Camfil 30/30 MERV 8 2-inch filter will be used to filter the inlet air. The filtered air should comply with ODEQ construction standard, OAC 252:626-9-3.b(5) which states that forced or induced draft aeration devices should be designed to ensure air introduced in the column is free from obnoxious fumes, dust, and dirt, as possible. The existing screened mushroom vent will be used for the air exhaust.

Proposed Equipment Installation

Drawings for the aeration equipment installation are included in Appendix A and cut sheets for selected equipment are included in Appendix B. Installation of aeration equipment includes the following elements:

- A 2 hp, NSF 61 certified surface aerator. The surface aerator shall be disinfected with a low concentration solution prior to installation in the clearwell (approx. 0.02% sodium hypochlorite in accordance with AWWA C652-11 Disinfection of Water Storage Facilities Section 4.4.6 Equipment and Personnel).
- A 3 hp, NSF 61 certified submersible pump. The submersible pump shall be disinfected with a low concentration solution prior to installation in the clearwell (approx. 0.02% sodium hypochlorite in accordance with AWWA C652-11 Disinfection of Water Storage Facilities Section 4.4.6 Equipment and Personnel).
- Installation of two bolted pipes to secure the aeration unit. One of the pipes will convey spray aeration flow to the top of the reservoir.
- Two PVC nozzles for the spray aeration system.
- A 120 VAC tank mixer.
- Installation of 120 VAC air supply fan. At a pressure drop across the fan and screen of 0.75 in W.C., the selected fan air flow rate is approximately 130 scfm, which is sufficient to facilitate TTHM reduction. To confirm this design target is met, air flow will be measured using a hand held anemometer.
- Two penetrations for aeration power supply.

Process Control

The following process control will be required for aeration equipment:

- Panel with run status lights to indicate whether the aerator and pump are operating and ability to start/stop aerator and pump. The start and stop times of the surface aerator and spray aeration pump will be recorded daily as part of the data logging process.
- Two watt meters will be added between the panel and the starters of the surface aerator and the spray aeration pump. The watt meters will record the actual power consumption of each technology over time.
- Switch with the ability to start/ stop the ventilation fan. Fan speed variation not planned as part of testing. The start and stop times of the ventilation fan will be recorded daily as part of the data logging process.
- Two floor plates with EPDM pads will be placed below the aerator and submersible pump to prevent contact with the reservoir floor if drained for maintenance.

Air Quality Emissions

Given the maximum influent flow of 80 gpm and assuming a conservative maximum TTHM concentration at the clearwell of 120 µg/L, approximately 0.115 lb/day of VOC would be released if all TTHMs were removed and if the WTP operated continuously for the entire day at those conditions. This is well below the regulatory limit of 2 lb/day.

Project Schedule

The project team recommends the aeration equipment to be operated during the Fall of 2014 to collect initial data. The following schedule in is envisioned and any efforts to expedite it will be helpful to better meet this objective.

Table 3-4 Preliminary Project Schedule

Task	Date
Agency Review Submittal – Draft Version	6/28/2014
Agency Review Period (30 business days)	8/1/2014
Final Design Submittal	8/15/2014
Equipment Installation	Week of 10/13/2014
Begin Test Program	10/20/2014

The testing period will include the following test phases:

- Baseline Conditions (normal operation)
- Active ventilation
- Tank mixer and active ventilation
- Surface aerator with active ventilation
- Surface aerator with passive ventilation
- Spray aeration system with active ventilation
- Spray aeration system with passive ventilation.

Initially, it was planned that each test phase will be continued for a one week period. However, based on the small size of the OTOE- Missouria tribe WTP clearwell, steady state condition in any test phase can be achieved within a few hours of operation. As such, the testing schedule has been modified such that two test phases can be tested per week. Each test phase will be operated for a minimum of 2 days. The same number of samples, as were originally planned, will be collected during this modified test schedule – the sample collection will only occur within a shorter duration of time. Also, depending on the results observed, any test phase will be extended as needed, until satisfactory data have been collected.

4.0 Pilot Testing Protocol

The aeration equipment installation will be performed in accordance with the guidelines prescribed in AWWA Standard C652-11 "Disinfection of Water Storage Facilities". A water quality sampling plan will be implemented at the OMT WTP and in the distribution system to evaluate the reduction of TTHM concentrations with aeration equipment, as well as the impact on other drinking water quality parameters including chlorine residual. The following sections summarize the proposed equipment installation, sampling and monitoring program.

Equipment Installation

All equipment and materials to be installed within the reservoir for aeration testing are NSF 61 certified. The aeration equipment will be installed (and uninstalled) "live" while the WTP and the clearwell are still online. It is planned to have all the aeration equipment installed at one time, and uninstalled at one time as well. If for any reason, additional installation, or troubleshooting is necessary which require clearwell access, guidelines prescribed in AWWA Standard C652-11 will be adhered to during each entry event. Prior to the installation of the aeration equipment, the clearwell floor will be cleaned of all flocculated material, silt, sediment, sand, and any other accumulated debris. The will be done by the equipment installer utilizing the proprietary HydroDyne Cleaning System. The following sections describe details of the operational plan of the WTP and the clearwell during the installation and uninstallation process, the associated sampling plan, and a contingency plan in the event of a total coliform sample results in total coliform positive.

Standard Operational Procedure during Aeration Equipment Installation/ Uninstallation

The aeration equipment installation and uninstallation will be performed in accordance with AWWA Standard C652-11, Section 4.4. Specific items to be considered during the installation/ uninstallation process are mentioned below, these items have been adapted directly from AWWA Standard C652-11, Section 4.4:

- A pre-job meeting (via conference call) will be held that includes the WRF 4441 project team members, OTOE- Missouria WTP personnel, and the equipment installation contractor. During this meeting the equipment installation and uninstallation processes will be reviewed including disinfection procedures, time restrictions, diving conditions, and safety procedures.

- During the equipment installation and uninstallation in the clearwell, a positive flow into the clearwell will be maintained, and flow rates into and out of the clearwell will be minimal.
- Equipment and personnel entering the clearwell will be cleaned and disinfected immediately prior to entry into the clearwell. The access hatch at the top of the clearwell and the immediate area surrounding the access hatch will be cleaned prior to equipment installation and uninstallation. The method of equipment disinfection can be submersion in, spraying with, or sponging with disinfectant solution. The diver and the clothing shall be disinfected after the diver is suited up and on top of the clearwell.
- Water quality sampling and analyses will be performed prior to, during, and upon completion of installation of the aeration equipment in the clearwell. A detailed description of the water quality sampling and analyses to be performed is described in the following sub-section.
- All equipment used during the installation/ uninstallation process will be maintained in such a fashion that water quality is not affected. Divers shall be completely encapsulated with no bare skin exposed. Diving clothing shall be of the dry-suit type and shall be in good condition, free from tears, scrapes, unrepaired areas, or other imperfection that may impair the integrity of the suit. There shall be no contact of the mouth or head with the water. The head shall be fully encapsulated by one or a combination of helmet or dry suit hood with full-face mask.
- Divers shall have communication in accordance with federal, state, and local regulations.
- Because of the hazardous nature of this work, which combines elevated work, confined space entry, and diving, the contractor performing the work shall comply with all federal, state, and local regulations. All diving operations will be conducted by certified divers who have graduated from an ACDE Approved Commercial Diving Course. Personnel on the dive team shall also be OSHA Confined Space Certified. All personnel on the dive team shall be free of communicable disease and shall not have been under a physician's care within the seven-day period prior to entering of the clearwell. The

American Red Cross or an equivalent agency shall certify all dive team members in the use of CPR and First Aid.

- The dive team shall comply with all applicable local, state, and federal safety requirements. The equipment installation contractor shall have a comprehensive safety manual on-site, which addresses all of the potential hazards. The safety manual shall include certifications of all safety and emergency response requirements at the site. The contractor shall have a method and the equipment readily available for the extraction of an injured diver and a method for lowering a person to the ground who is incapacitated.

Water Quality Sampling During Aeration Equipment Installation/ Uninstallation

Water quality sampling will be performed prior to, during, and after the aeration equipment installation and uninstallation processes in order to ensure that the treated water quality meets all applicable water quality standards and is safe to be pumped to the distribution system. The water quality sampling procedure is described briefly below, and has been directly adapted from AWWA Standard C652-11, Section 5:

- An initial water quality analysis of the clearwell water will be performed prior to equipment installation/ uninstallation. At a minimum, measured water quality parameters will include chlorine residual, turbidity, pH, and alkalinity. The methods used for analyses of water quality parameters will be in accordance with the latest edition of *Standard Methods for the Examination of Water and Wastewater*. The results shall be recorded. If the installation/ uninstallation process requires more than one day, similar water quality parameters will be sampled and recorded every day prior to the commencement of work inside the clearwell.
- For every day of work during the installation/ uninstallation process, a total coliform sample will also be collected and analyzed from the clearwell. As suggested by ODEQ, all total coliform samples collected during this project (during equipment installation and demonstration testing) will be labeled as “non-compliance” samples in the sample chain of custodies.
- If the total coliform test shows the presence of coliform bacteria, the WTP and the clearwell will be taken offline and disinfected. Repeat samples shall be taken until two

consecutive samples are negative. The WTP and the clearwell will be placed in service only after two consecutive repeat samples show negative total coliform bacteria.

- Clearwell samples will be collected from a sample tap on the outlet piping of the clearwell. This sampling point currently does not exist, and will be installed prior to commencement of the testing. It will be ensured that the sample collected is actually from water that has been in the storage facility.
- For every total coliform sample collected from the outlet piping of the clearwell, an additional chlorine residual and total coliform sample will also be collected from water flowing into the clearwell. This will be done to determine if coliforms are present in the feed water to the clearwell.

Contingency Planning for Meeting Water Demand during Aeration Equipment Installation/ Uninstallation

It has been noted previously that the OTOE- Missouria WTP is the sole source for the production of drinking water for the community. Additionally, there are no emergency interconnects with any other neighboring community. As such, contingency planning is key to ensure that water supply to the community is not disrupted during the aeration equipment installation and uninstallation processes. The following measures will be adopted during the equipment installation/ uninstallation processes as part of contingency planning:

- Outside of the WTP, the tribe has a 120,000 gallon distribution system standpipe that will serve as the primary storage of water during the aeration equipment installation/ uninstallation period. Prior to the commencement of any installation/ uninstallation activities, water will be pumped into this standpipe and it will be filled to the maximum capacity allowable by hydraulic constraints.
- Prior to commencement of any installation/ uninstallation period, it will be ensured that the chlorine residual in the treated water being pumped to the distribution system standpipe is high, approximately 3.5 mg/L. This ensures that even after a comparatively long hydraulic residence time within the standpipe, the water in the distribution system is not depleted of chlorine residual.
- On the days of equipment installation/ uninstallation, activities will be initiated as early in the day as possible. This allows for collection of total coliform samples and shipping

them to the Laboratory on the same day that equipment installation/ uninstallation is performed.

- While the installation/ uninstallation processes will be performed "live" with the WTP and clearwell in service, water flow rates into and out of the clearwell will be kept to a minimum. Full production at the WTP and pumping with high service pumps will only resume once the equipment installation/ uninstallation processes are complete.
- In case the total coliform sample result from the Laboratory is "positive" indicating presence of coliform bacteria, the following response actions will be executed:
    - The WTP and the clearwell will be immediately taken offline and isolated from the distribution system
    - All WTP processes and clearwell will be disinfected using a high dose of chlorine
    - Post disinfection, the water with the high chlorine residual will be drained, collected and safely disposed of
    - A chlorine residual and total coliform sample will be collected from the clearwell effluent post disinfection
    - An additional chlorine residual and total coliform sample will be collected from a representative location in the distribution system
    - The WTP and the clearwell will not be put back in service until two consecutive total coliform samples from the clearwell effluent are "negative"
    - The distribution system standpipe will be used for the supply of potable water until the WTP and clearwell can be put back in service
    - Depending on the results of the initial total coliform sample, and any repeat samples, the tribe will issue boil water advisories or boil water notices to their community in accordance with applicable federal, state, and local regulations
    - The tribe will also send out communications to their community describing the situation and urging conservation practices until the water supply can be restored at the WTP
    - Once the WTP and the clearwell has been put back in service, another chlorine residual and total coliform sample will be collected from a representative location in the distribution system.

Baseline Sampling

Sampling will be conducted prior to the start of the aeration testing to identify baseline water quality conditions. This baseline water quality sampling will be conducted with a pre-chlorination strategy online to meet the conditions described in Section 2.0. The sampling will follow the same format as for the aeration testing period described in the next subsection. Baseline sampling data will be obtained for two 8-hour days through sampling and monitoring. It should be noted that the influent samples must be collected when the WTP is operating to assure the sample is representative of water entering the tank. The effluent samples must be collected when the booster pumps are running to assure the sample is representative of water leaving the tank.

Aeration Testing Period

During the aeration testing period, the following water quality parameters will be monitored at each sampling location as listed in Table 4-1. Samples will be collected during each phase of testing throughout the demonstration testing period. This plan includes monitoring for clearwell CT as discussed in Section 2.0 of this report. As discussed in Section 2.0, log inactivation of *Giardia* will be calculated for each set of field recorded values. Log inactivation of *Giardia* will be calculated separately for the WTP and the clearwell. However, the log inactivation calculations will not be performed on site, but calculated at the end of each day during testing. Instead, minimum or maximum values of field recorded parameters will be specified in the field log sheets. If designated staff is not available, or if any of the operational or water quality field recorded parameters are outside the specified levels for achieving adequate CT, then the aeration testing equipment will be turned off until acceptable CT testing conditions are met.

Laboratory analyses for this project will be conducted by Accurate Labs Inc. in Stillwater, OK, or American Water Central Laboratory in Belleville, IL. Accurate Labs Inc. is a ODEQ certified laboratory (Laboratory Certificate # 2014-084). American Water Central Laboratory is not an ODEQ certified laboratory, but has TNI (The NELAC Institute) accreditation – a program recognized in Oklahoma.

Table 4-1 Parameters to be monitored during aeration testing

Location	Parameter	Frequency
Raw Water	TOC & Bromide	Weekly
Clearwell Inlet (after WTP filters)	TTHM	Two samples during each testing phase
	HAA5	One sample during weeks of testing for baseline and aeration conditions surface and spray with ventilation
	TOC	Weekly when WTP online
	Free Cl_2 (field)	Hourly every day when WTP online and aeration testing ongoing
	pH (field)	Hourly every day when WTP online and aeration testing ongoing
	Temperature (field)	Hourly every day when WTP online and aeration testing ongoing
	Flow Rate (field)	Hourly every day when WTP online and aeration testing ongoing
Clearwell Outlet	TTHM	Two samples during each testing phase when booster pumps are on, collect additional sample prior to turning aeration equipment on (monitoring with donated THM-100 online analyzer also planned)
	HAA5	One sample during weeks of testing for baseline and aeration conditions surface and spray with ventilation
	Free Cl_2 (field)	Hourly every day when WTP and booster pumps are online and aeration testing ongoing (existing analyzer available for comparison)
	pH (field)	Hourly every day when WTP and booster pumps are online and aeration testing ongoing
	Temperature (field)	Hourly every day when WTP and booster pumps are online and aeration testing ongoing
	Flow Rate (field)	Hourly every day when WTP and booster pumps are online and aeration testing ongoing
	Level (field)	Hourly every day when WTP and booster pumps are online and aeration testing ongoing
Stage 2 Monitoring Site (Sampling Site Code: TTHM_01, Address: 24500 Windmill Road (Randy Gum)	TTHM	Once during each testing phase
	HAA5	Once during each testing phase
	Free Cl_2 (field)	Once during each testing phase
	pH (field)	Once during each testing phase
	Temperature (field)	Once during each testing phase

The TTHM_01 site (24500 Windmill Road (Randy Gum)) was selected because in the IDSE plan submitted by the OTOE-Missouria Tribe, it ranked # 1 in high TTHM formation and # 2 in high HAA5 formation. While not explicitly mentioned in Table 4-1, a few pH, free chlorine residual, TTHM and HAA5 samples will be collected from the tribe's other Stage 2 DBP monitoring site (Sampling Site Code: DBPMX, Address: 9251 cr 200, Red Rock, OK, 74651) for comparison. The exact number and timing of sample collection from this site will be determined based on the initial results observed at the TTHM_01 site.

As mentioned previously, it is recommended to measure air flow rate for reservoir ventilation. This monitoring should occur once per day during each of the weeks when ventilation equipment is turned on.

Chlorine Residual Management

Chlorine residual is continuously monitored at the WTP injection point to the distribution system. The amount of chlorine residual reduction caused by aeration equipment is expected to be minimal. Chlorine residual will continue to be monitored at the WTP effluent and clearwell effluent at the frequency specified in Table 4-1 to determine if there is a need for increased chlorine dosing.

APPENDIX A

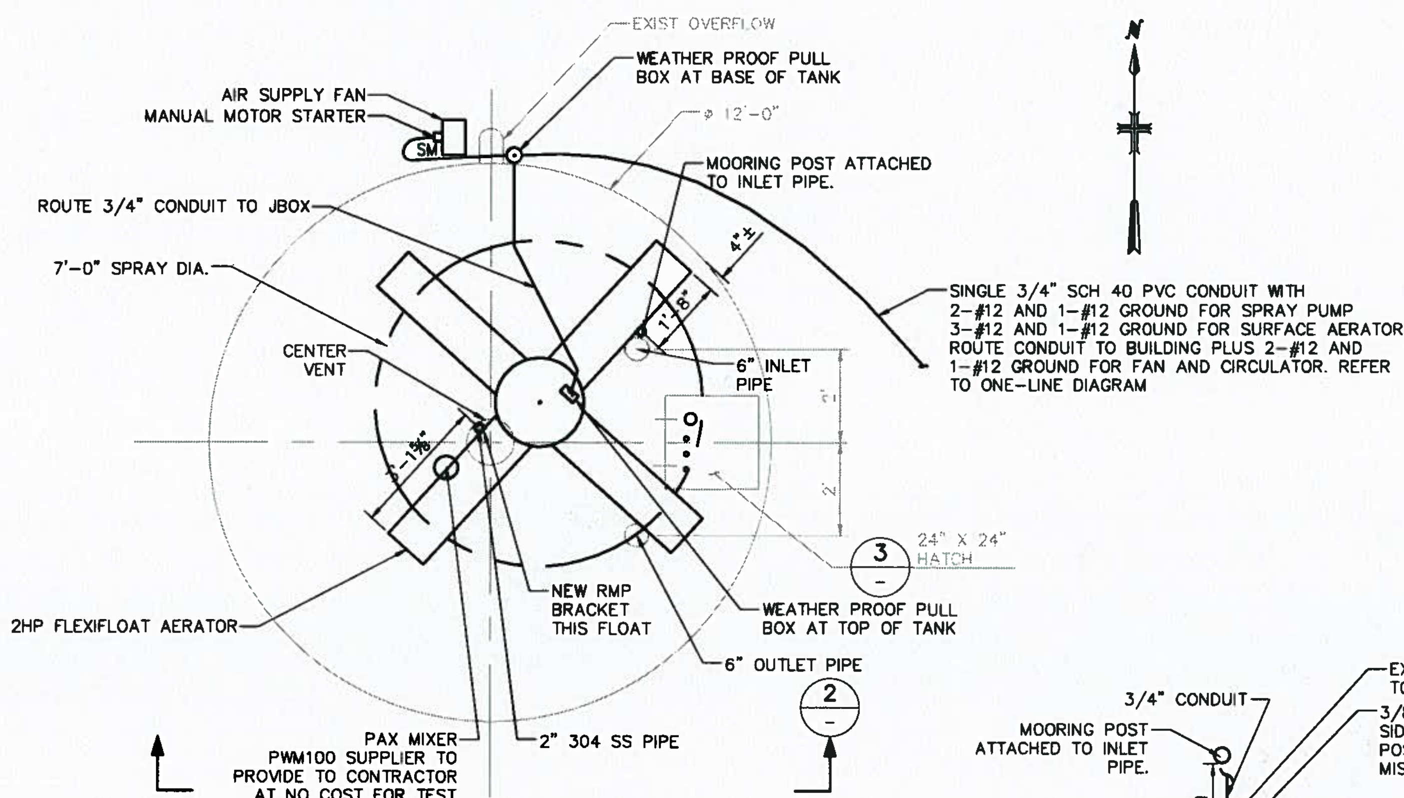
Aeration Drawings

NOTES:

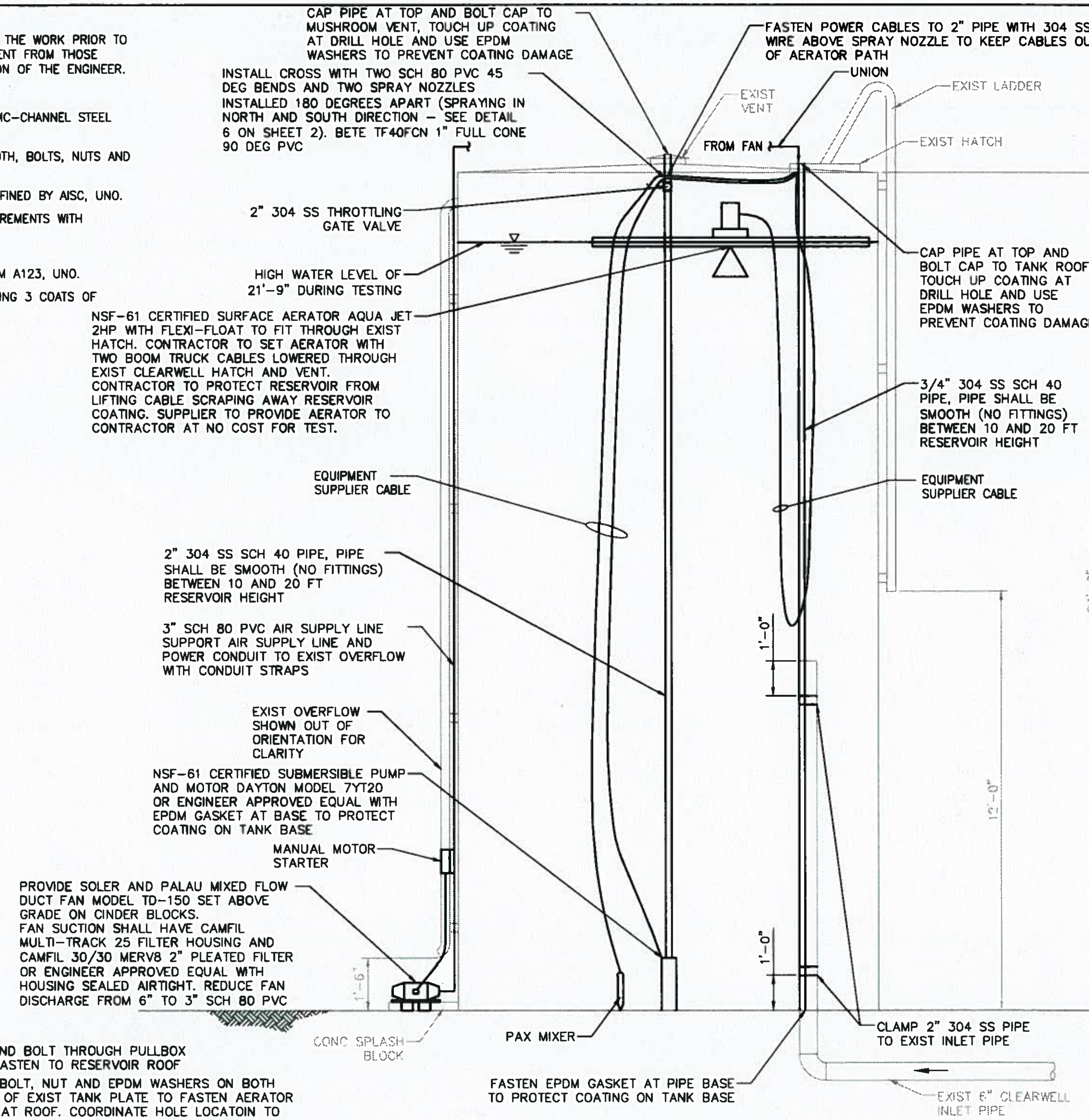
1. STRUCTURES, EQUIPMENT AND OTHER EXISTING INSTALLATIONS SHALL BE PROTECTED FROM DAMAGE BY THE CONTRACTOR. ANY DAMAGES CAUSED BY THE CONTRACTOR OR CAUSED DUE TO WORK BEING DONE SHALL BE RESTORED TO OWNER'S SATISFACTION.
2. CONTRACTOR SHALL ADHERE TO ADOPTED BUILDING, ELECTRICAL & FIRE CODE. OTHER CITY CODES THAT APPLY TO THIS PROJECT AND NOT NOTED ABOVE SHALL BE ADHERED TO.
3. FACILITIES WHICH ARE NOT SPECIFICALLY LOCATED WITH HORIZONTAL AND VERTICAL CONTROLS ARE LOCATED APPROXIMATELY TO THE BEST INFORMATION AVAILABLE.
4. THE SEPARATION OF WATER AND SEWER MAINS SHALL CONFORM TO ODEQ REQUIREMENTS.
5. ALL EXISTING WATER LINES ARE TO REMAIN IN CONTINUOUS SERVICE DURING CONSTRUCTION.
6. ALL MATERIALS IN CONTACT WITH POTABLE WATER SHALL BE NSF 60/61 CERTIFIED.
7. ALL RESERVOIR COATING DAMAGE AND EXPOSED CARBON STEEL AS RESULT OF THIS CONSTRUCTION TO BE REPAIRED. CONTRACTOR TO FOLLOW ALL COATING SUPPLIER RECOMMENDATIONS FOR SURFACE PREPARATION AND FIELD APPLICATION.
8. ALL RESERVOIR PENETRATIONS AS RESULT OF THIS CONSTRUCTION SHALL BE SEALED AIRTIGHT UNLESS SPECIFIED OTHERWISE.
9. EQUIPMENT SHALL BE DISINFECTED WITH A LOW CONCENTRATION SOLUTION (APPROX. 0.02% SODIUM HYPOCHLORITE) PRIOR TO INSTALLATION IN THE CLEARWELL IN ACCORDANCE WITH AWWA C652-11 DISINFECTION OF WATER STORAGE FACILITIES SECTION 4.4.6 EQUIPMENT AND PERSONNEL.
10. BEFORE START OF EQUIPMENT INSTALLATION, CONTRACTOR TO HAVE DIVERS REMOVE SEDIMENT AT RESERVOIR BASE USING LIQUID ENGINEERING HYDRODYNE OR ENGINEER APPROVED EQUAL SYSTEM WHICH DOES NOT REQUIRE DRAINING THE TANK.
11. CONTRACTOR TO REMOVE ALL INSTALLED EQUIPMENT AT END OF WEEK TEST AND ASK OWNER ON SALVAGING EQUIPMENT. ALL REMAINING ITEMS TO BE TRANSPORTED TO LANDFILL

STRUCTURAL NOTES:

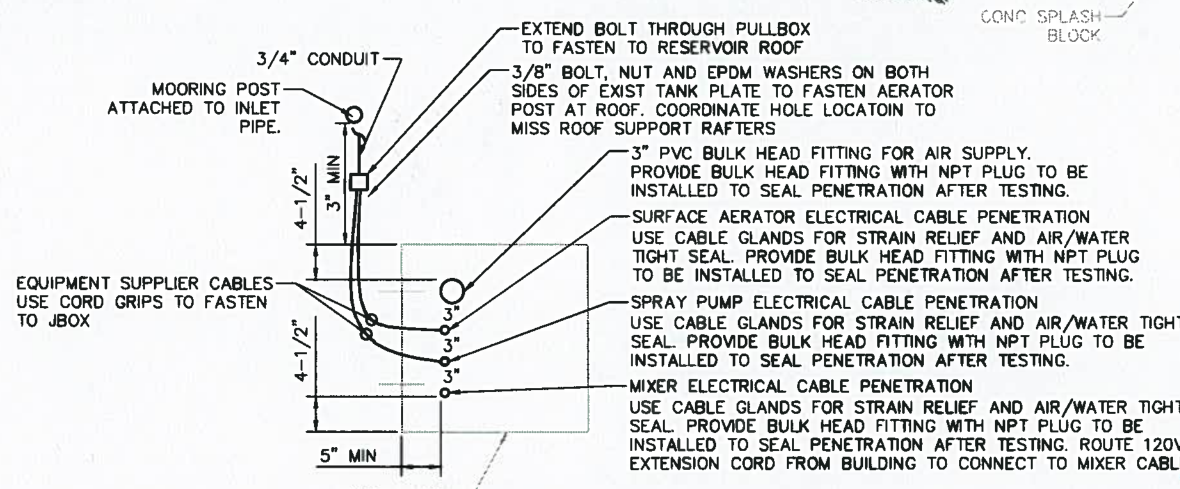
1. THE CONTRACTOR SHALL FIELD VERIFY EXISTING CONDITIONS PERTINENT TO THE WORK PRIOR TO MATERIAL FABRICATION AND/OR CONSTRUCTION. FIELD CONDITIONS DIFFERENT FROM THOSE NOTED ON THE DRAWINGS SHALL BE PROMPTLY BROUGHT TO THE ATTENTION OF THE ENGINEER.
2. STEEL
   A. STRUCTURAL STEEL PLATES, ANGLE STEEL, C-CHANNEL STEEL, AND MC-CHANNEL STEEL SHALL CONFORM TO ASTM A36.
   B. WHERE ASTM A325 BOLTS ARE SPECIFIED, USE ASTM A563 NUTS. BOTH, BOLTS, NUTS AND WASHERS SHALL BE HOT DIP GALVANIZED PER ASTM A153.
   C. ALL NUTS SHALL BE TORQUED TO A "SNUG TIGHT" CONDITION, AS DEFINED BY AISC, UNO.
   D. WORK IN CONFINED SPACES SHALL BE PERFORMED PER OSHA REQUIREMENTS WITH ADEQUATE VENTILATION REQUIRED.
3. COATINGS
   A. ALL STRUCTURAL STEEL SHALL BE HOT DIPPED GALVANIZED PER ASTM A123, UNO.
   B. ALL DAMAGED COATINGS SHALL BE RE-APPLIED OR TOUCHED-UP USING 3 COATS OF TNEMEC N140F OR ENGINEER APPROVED EQUAL.



1 TANK ROOF PLAN
SCALE: 1" = 2'



2 SECTION
SCALE: 1" = 2'



3 EXISTING HATCH DETAIL

REGISTERED PROFESSIONAL ENGINEER DOUGLAS LEE SMITH 18145 OKLAHOMA
8-15-2014

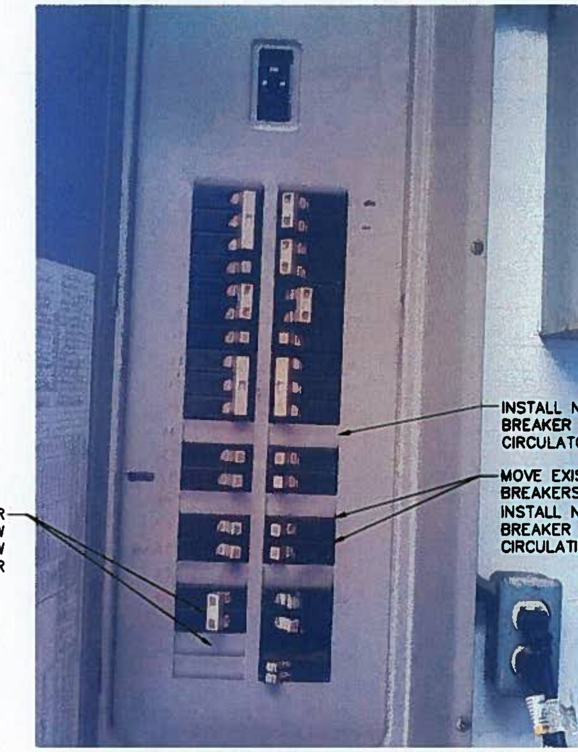
JACOBS
101 NORTH FIRST AVENUE
SUITE 3100
PHOENIX, ARIZONA 85003
602-253-1200

AMERICAN WATER
CEC
Corona Environmental Consulting, LLC

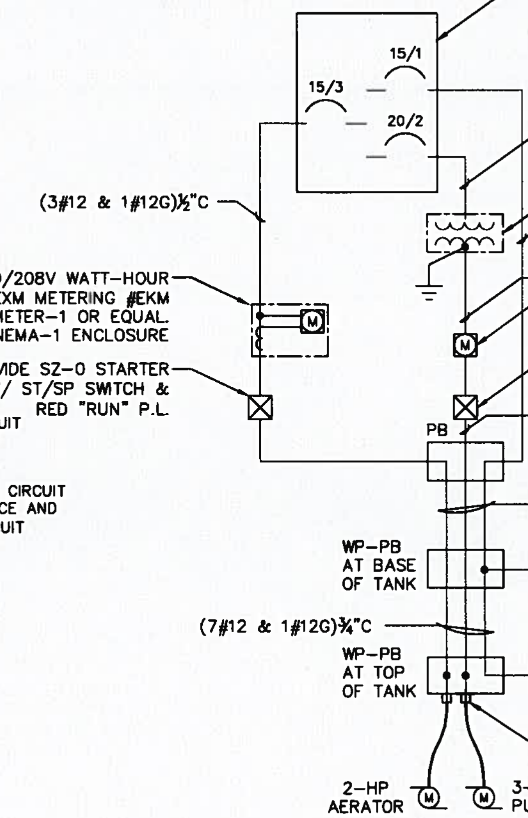
SHEET TITLE: CLEARWELL MODIFICATIONS OTOE MISSOURIA TRIBE WTP
PROJECT TITLE: EPA AERATION TTHM REDUCTION PILOT

SCALE	DESIGNED	DATE	BID NO.	SHT.
HORIZ.	BA	08/14		1
VERT.	DRAWN MG	AS-BUILT	PROJECT NO.	1 OF 2

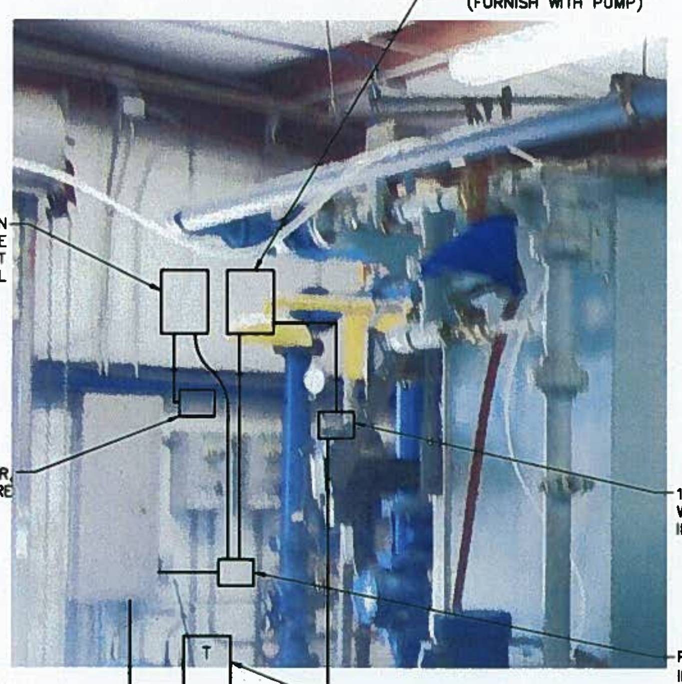
1 – BOOSTER PUMP DISCHARGE SAMPLE POINT
SCALE: N.T.S.



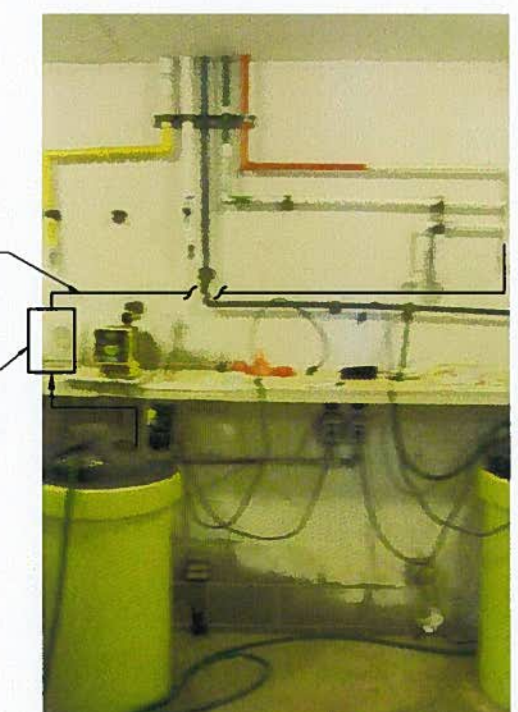
2 – RELOCATION OF BREAKERS
SCALE: N.T.S.



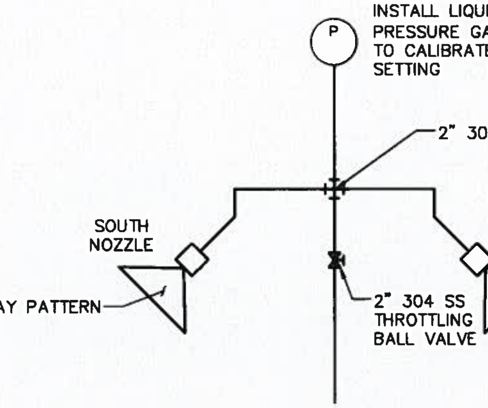
5 – ELECTRICAL ONE-LINE DIAGRAM
SCALE: N.T.S.



3 – MOUNTING LOCATION FOR STARTERS
SCALE: N.T.S.



4 – PRE-CHLORINATION FEED POINT
SCALE: N.T.S.



6 – SPRAY AERATION NOZZLE DETAIL
SCALE: N.T.S.

REGISTERED PROFESSIONAL ENGINEER
DOUGLAS LEE SMITH
18145
OKLAHOMA
8-15-2014

DATE	REVISION	BY

ENGINEER
JACOBS
101 NORTH FIRST AVENUE
SUITE 3100
PHOENIX, ARIZONA 85003
602-253-1200

AMERICAN WATER
CEC
Corona Environmental Consulting, LLC

SHEET TITLE: OTOE MISSOURIA TRIBE WTP BUILDING MODIFICATION DETAILS

PROJECT TITLE: EPA AERATION TTHM REDUCTION PILOT

SCALE	DESIGNED	DATE	BID NO.	SHT.
HORIZ.	SA	08/14		2
VERT.	DRAWN MG	AS-BUILT	PROJECT NO.	2 OF 2

APPENDIX B

Equipment Cut Sheets

GRAINGER
FOR THE ONES WHO GET IT DONE

Pump/Motor with Control Box, 60 GPM, 3 HP

DAYTON

Price: $3,058.00 / each

Deliver one time only

Auto-Reorder Every 1 Month

Typically in Stock

Item # **7YT20**
Catalog Page # **3742**
Mfr. Model # **7YT20**
Shipping Weight **60.33 lbs.**
UNSPSC # **26101611**

Country of Origin **Varies**Country of Origin is subject to change.

close x

Using 360° Viewing:

1. Rotate: Use top-to-bottom, side-to-side by use of mouse arrow.
2. Zoom In: Double click on image.
3. Zoom Out/Reset: Put photo at full zoom & then double click.

Technical Specs

Item	**Pump/Motor with Control Box**
Type	**Deep Well Submersible**
Number of Wires	**3**
Control Box Required	**1LZW3**
GPM	**60**
HP	**3**
Voltage	**230**
Amps AC	**14**
Phase	**1**
Stages	**8**
GPM @ Vertical Depth to Water @ 20 Ft @ 30 PSI	**74**
GPM @ Vertical Depth to Water @ 100 Ft @ 30 PSI	**49**
GPM @ Vertical Depth to Water @ 20 Ft @ 50 PSI	**63**
GPM @ Vertical Depth to Water @ 100 Ft @ 50 PSI	**32**
Built-In Check Valve	**No**
Pump Material	**Stainless Steel**
Impeller Material	**Glass Filled Noryl**
Discharge Port (In.)	**2**
Flow Ranges (GPM)	**30-75**
Max. Operating Temp. (F)	**130**
Motor	**Capacitor-Start, Capacitor-Run**
Pump Bearings	**Ceramic/Rubber**

Shaft Material	**Splined Stainless Steel**
Tank PSI	**20 30 40 50 60**
GPM of Water @ 20 Ft @ 30, 50 PSI	**74 63**
GPM of Water @ 40 Ft @ 30, 50 PSI	**70 58**
GPM of Water @ 60 Ft @ 30, 50 PSI	**65 50**
GPM of Water @ 80 Ft @ 30, 50 PSI	**56 42**
GPM of Water @ 100 Ft @ 30, 50 PSI	**49 32**
GPM of Water @ 125 Ft @ 30, 50 PSI	**39 -**
GPM of Water @ 150 Ft @ 30, 50 PSI	**28 -**
GPM of Water @ 175 Ft @ 30, 50 PSI	**27 -**
GPM of Water @ 200 Ft @ 30, 50 PSI	**- -**
GPM of Water @ 250 Ft @ 30, 50 PSI	**- -**
GPM of Water @ 300 Ft @ 30, 50 PSI	**- -**
GPM of Water @ 350 Ft @ 30, 50 PSI	**- -**
GPM of Water @ 400 Ft @ 30, 50 PSI	**- -**
GPM of Water @ 450 Ft @ 30, 50 PSI	**- -**
GPM of Water @ 500 Ft @ 30, 50 PSI	**- -**

Pump-Motor Shell	**Corrosion-resistant Stainless Steel**
Max. Head (Ft.)	**575**
Well Capacity	**Very High**
Recommended Tank	**1XHH4**
SF Amps	**17.0**
Motor Enclosure	**Totally Enclosed Nonventilated**
Includes	**1CXC1, 1LZP3, 1LZW3**

Compliance and Restrictions

None

GRAINGER
FOR THE ONES WHO GET IT DONE

Home / HVAC and Refrigeration / Duct Fans and Accessories / Inline Duct Fans /

View Product Family

Mixed Flow Duct Fan, 8-3/8 In. L, Ball

SOLER & PALAU

Price: $217.00 / each

Typically in Stock

☐ AddRepair & Replacement Coverage for $55.95 each.

Item # **3CGA6** Mfr. Model # **TD-150** UNSPSC # **40101604**

Catalog Page # **4126** Shipping Weight **7.55 lbs.**

Country of Origin **Spain**Country of Origin is subject to change.

close x

Using 360° Viewing:

1. Rotate: Use top-to-bottom, side-to-side by use of mouse arrow .
2. Zoom In: Double click on image.
3. Zoom Out/Reset: Put photo at full zoom & then double click.

Technical Specs

Item	**Mixed Flow Duct Fan**	CFM @ 1.000-In. SP	**35**
Housing Material	**Thermoplastic**	Max. Inlet Temp.	**104 Degrees F**
Fits Duct Dia.	**6"**	Inlet and Outlet Dia.	**5-7/8"**
Voltage	**120**	Hz	**60**
Max. Amps	**0.54**	Phase	**1**
Max. Wattage	**65/54**	Motor HP	**1/10**
Number of Speeds	**2**	Motor RPM	**2300/1700**
Housing Dia.	**7-7/8"**	Motor Enclosure	**Totally Enclosed**
Length	**8-3/8"**	Bearing Type	**Ball**
CFM @ 0.000-In. SP	**293/218**	Flange Width	**1-1/8"**
CFM @ 0.125-In. SP	**273/193**	Speed Control	**Mfr. No. 1DGV1**
CFM @ 0.250-In. SP	**250/163**	Mounting Position	**Horizontal or Vertical**
CFM @ 0.375-In. SP	**227/128**	Standards	**C-UL-US**
CFM @ 0.500-In. SP	**206/105**	Includes	**Mounting Bracket**
CFM @ 0.750-In. SP	**131/24**		

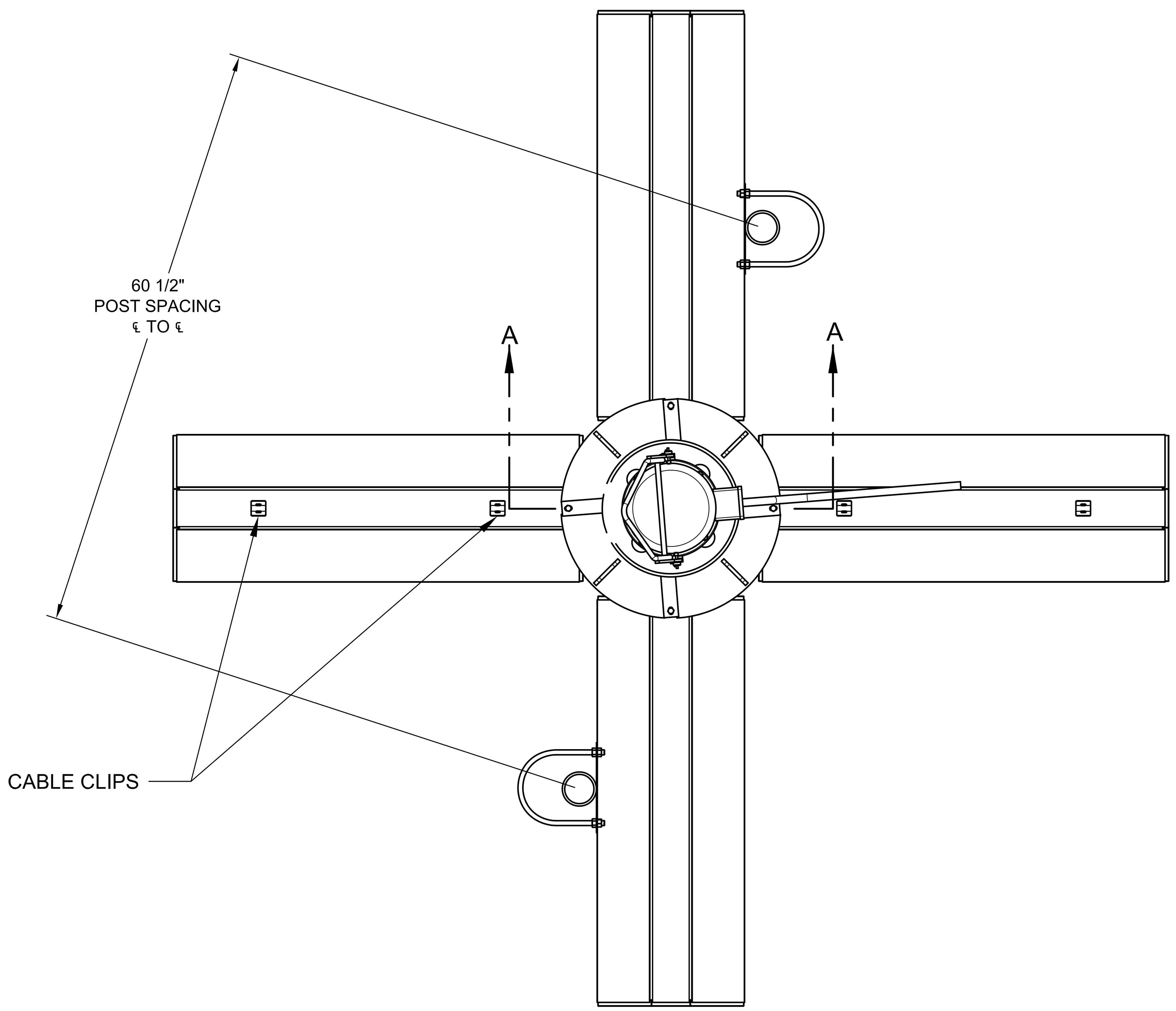
Compliance and Restrictions

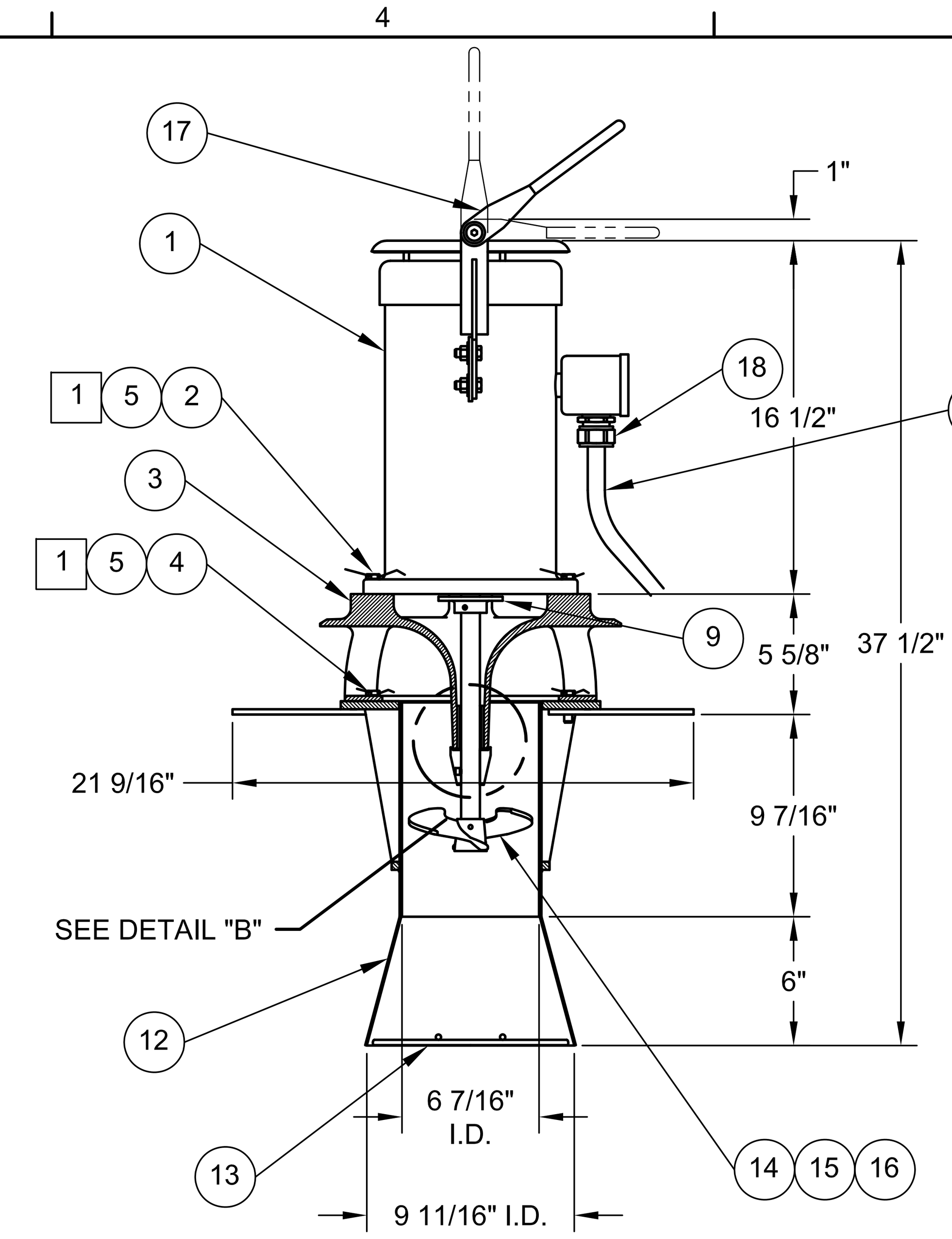
None

Documentation

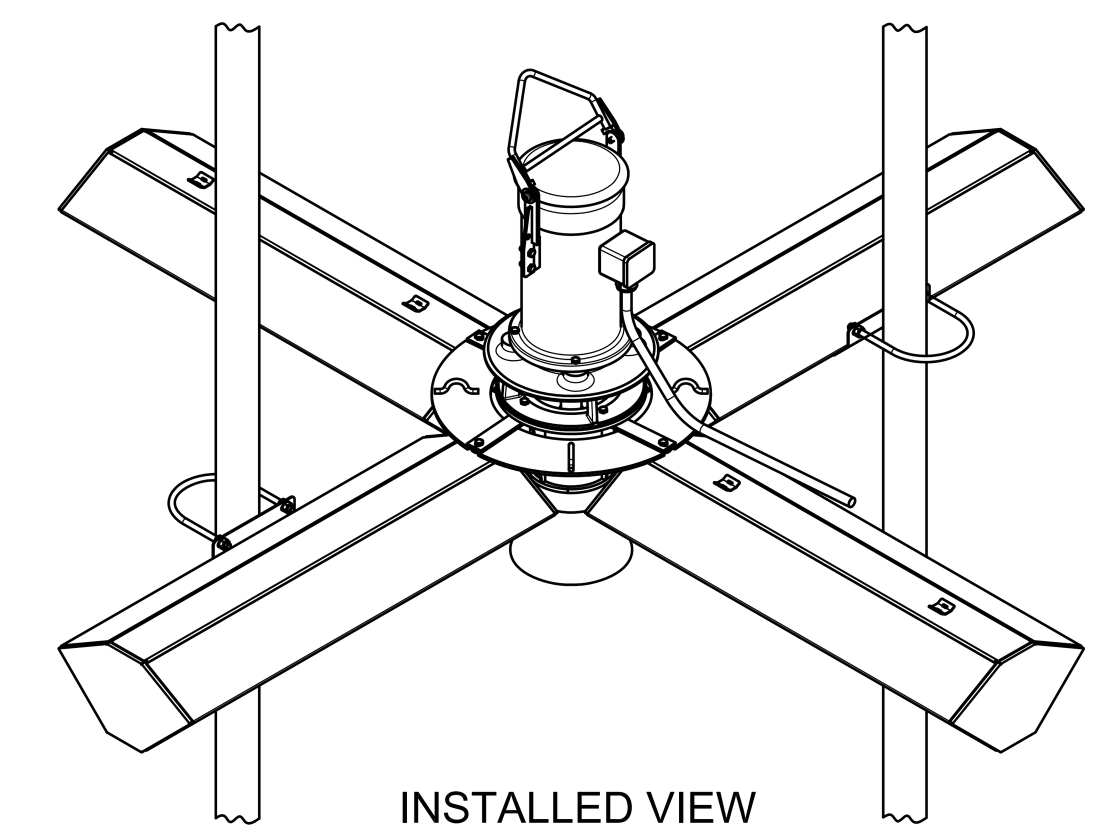
TD Silent Brochure
TD Spec Sheet
TD Tech Spec Sheet

Alternate Products

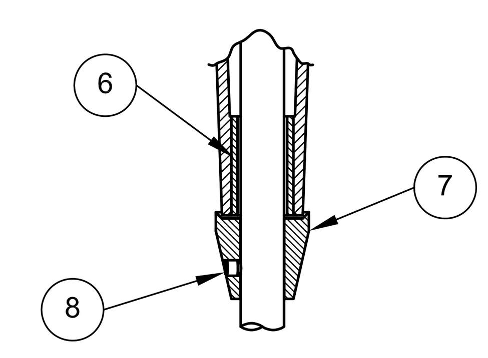




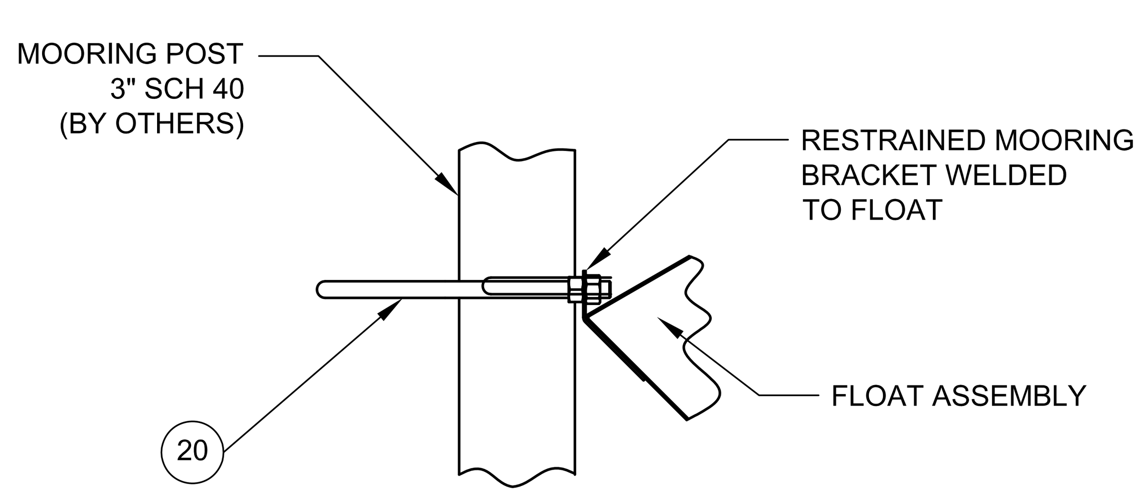
SECTION "A-A"



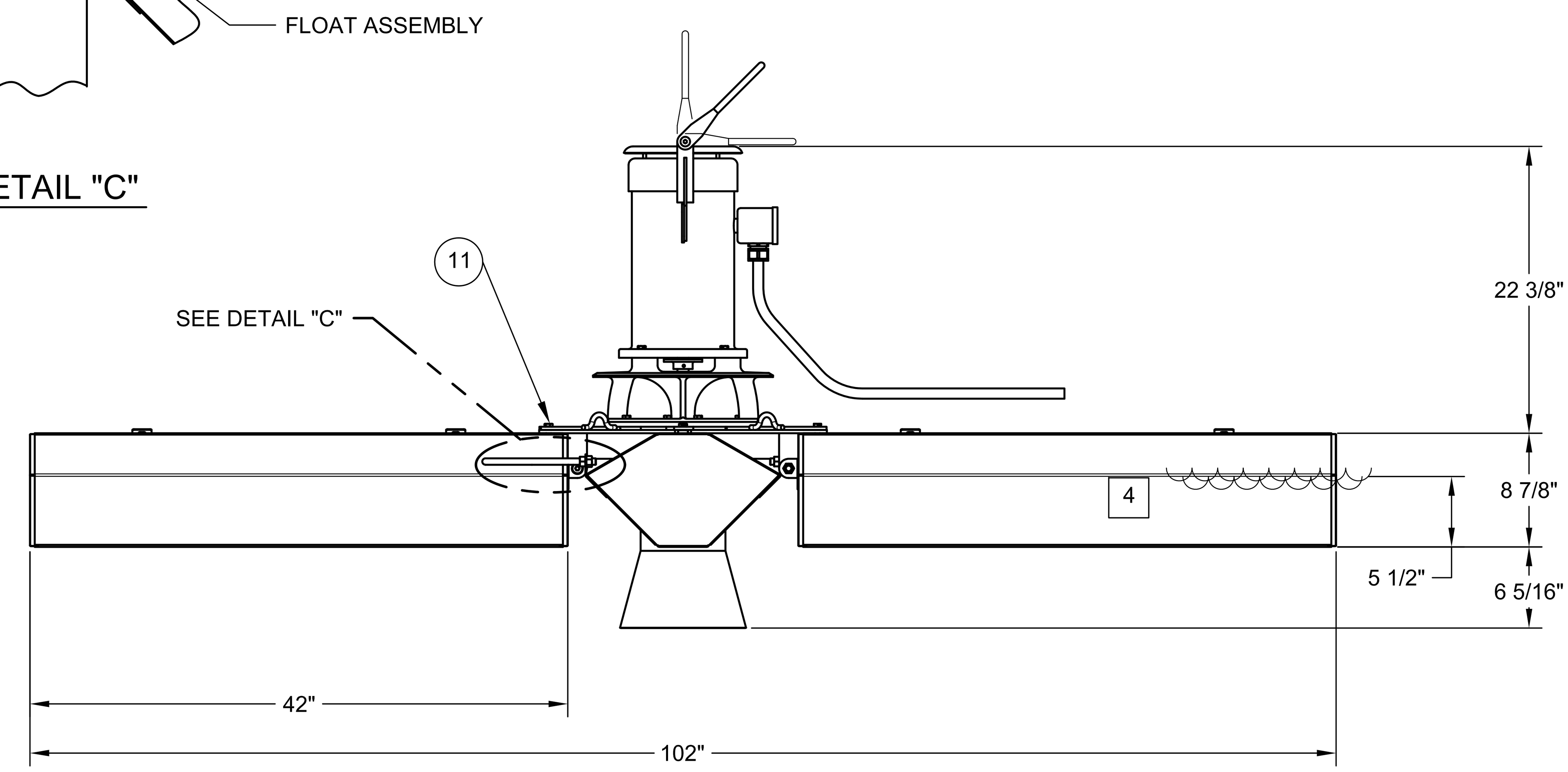
INSTALLED VIEW

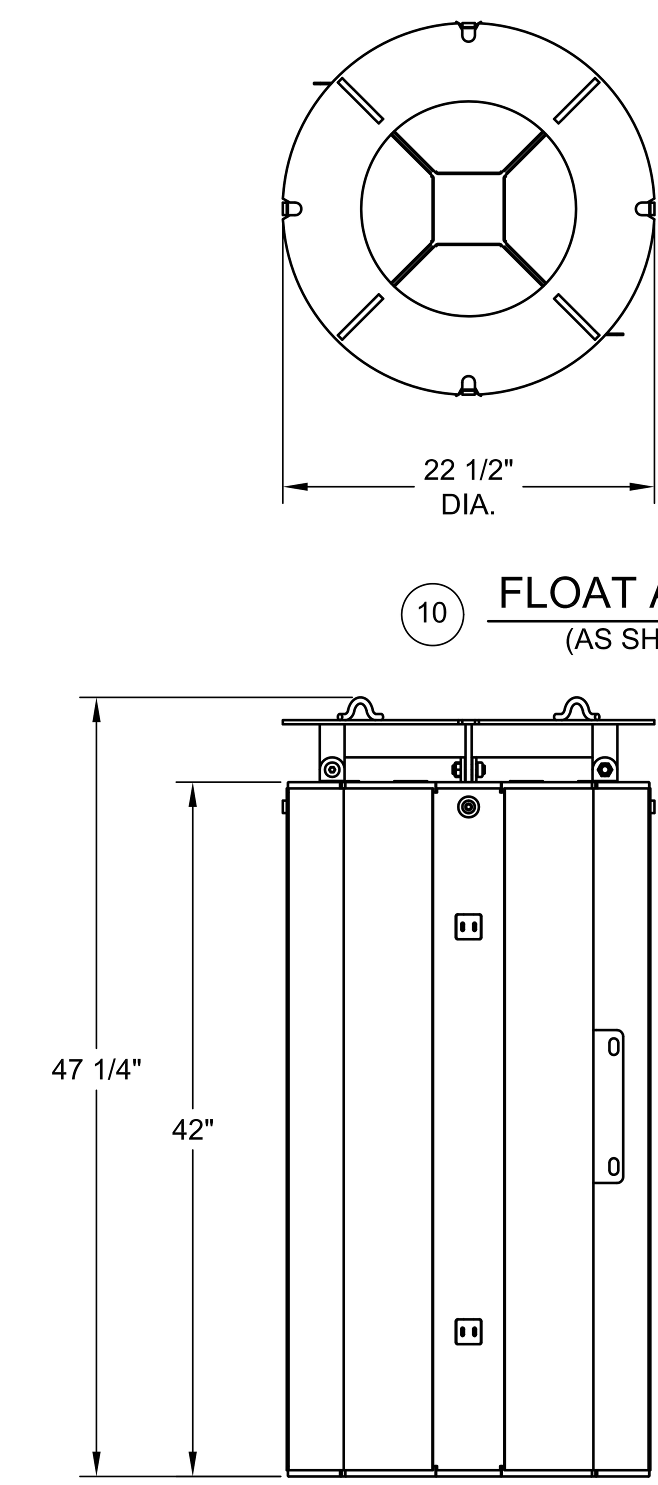


DETAIL "B"



DETAIL "C"





FLOAT ASSEMBLY
(AS SHIPPED)

1. THESE BOLTS ARE SAFETY WIRED IN PLACE.
2. FLOAT SKINS ARE 16 GA. 316 STAINLESS STEEL. FLOAT IS FILLED WITH TWO COMPONENT POLYURETHANE FOAM.
3. MOTOR SPECIFICATION:
   2 HP, 115/230 VOLT, 1 PHASE, 60 HERTZ, 1800 RPM, PREMIUM EFFICIENT, TEFC, 1.15 SERVICE FACTOR, CLASS F INSULATION, CONTINUOUS DUTY, NEMA DESIGN B, 65° C AMBIENT, WITH NORMALLY CLOSED THERMOSTAT AND 115 VOLT SPACE HEATER, ONE-PIECE 316 SS MOTOR SHAFT. MOTOR IS SUPPLIED WITH CHEVRON FM CSC EP2 FOOD GRADE GREASE AND IS COATED WITH AMERON'S AMERLOCK 2 (NSF-61 COMPLIANT) PAINT
4. OPERATING WATER LEVEL IS APPROXIMATELY 1/2" GREATER.
5. ITEMS 12 AND 13 ARE PART OF THE VOLUTE ASSEMBLY AND CANNOT BE PROVIDED SEPARATELY.
6. FLOAT ASSEMBLY CONSISTS OF SUPPORT BRACKET AND (4) STAINLESS STEEL FLOATS.
7. SHIPPED IN TWO (2) MAIN SECTIONS. AERATOR POWER SECTION/VOLUTE/CONE ASSEMBLY AND FLOAT ASSEMBLY.
8. MINIMUM HATCH CLEARANCE: 26" DIAMETER. INSTALL BY LOWERING FLOAT ASSEMBLY THROUGH HATCH AND ALLOW TO UNFOLD. LOWER POWER SECTION/VOLUTE/CONE THROUGH FLOAT CENTER. POSITION ON SUPPORT PLATE AND FASTEN IN PLACE WITH BOLTS PROVIDED.
9. WEIGHTS:
   POWER SECTION: 125 LBS.
   VOLUTE/CONE: 26 LBS.
   FLOAT ASSEMBLY (COMPLETE): 173 LBS.
   RESERVE BUOYANCY: 195 LBS.

ITEM	QTY	PART NUMBER	DESCRIPTION	MATERIAL	DWG
20	2		U-BOLT, 6" PIPE SIZE W/HEX NUTS	316 SS	
19	50 ft		CABLE, AWG #12-8 CONDUCTOR PWR & CNTRL CABLE	SEOOW	
18	1		COMPRESSION FITTING	SS	
17	1		SWIVEL LIFTING HARNESS	316 SS	
16	2		SET SCREW, PROPELLER	316 SS	
15	1		PROPELLER PIN	316 SS	
14	1		PROPELLER	316 SS	
13	1		INTAKE SCREEN	316 SS	
12	1		INTAKE CONE	316 SS	
11	4		BOLT, FLOAT	316 SS	
10	1		FLOAT ASSEMBLY	316 SS	
9	1		LABYRINTH SEAL GUARD	ACETRON GP	
8	4		SET SCREW	316 SS	
7	1		FLUID DEFLECTOR	ACETRON GP	
6	1		ANTI-DEFLECTION INSERT	ACETRON GP	
5	8 ft		SAFETY WIRE, .050 SOFT TEMPER	316 SS	
4	4		BOLT, DIFF HD	316 SS	
3	1		DIFFUSION HEAD	316 SS	
2	4		BOLT, MOTOR	316 SS	
1	1		MOTOR		

JOB NAME:
JOB LOCATION:

REV	ERN / ECO	DATE	BY	REVISION DESCRIPTION

AQUA-AEROBIC SYSTEMS, INC.

DO NOT SCALE DRAWING

UNLESS OTHERWISE SPECIFIED
FRACTIONAL DIMENSIONS +/- 1/16
ALL TWO PLACE DECIMALS +/- 0.010
ALL THREE PLACE DECIMALS +/- 0.005
ALL ANGLES +/- 1/2°
ANSI

MATERIAL: 316 SS
SIMILAR TO:
TYPE: AERATOR
DRAWN BY: JAK DATE: 2014-03-31
CHECKED BY: DATE:
WEIGHT: 325 LBS SHEET: 1 OF 1

DRAWING NAME: AERATOR ASSEMBLY, MODEL SS-PW, 2HP, FLEXIFLOAT
DRAWING NUMBER: 2802202 SCALE: 1:10 SIZE: D

- Find a Rep
- Blog

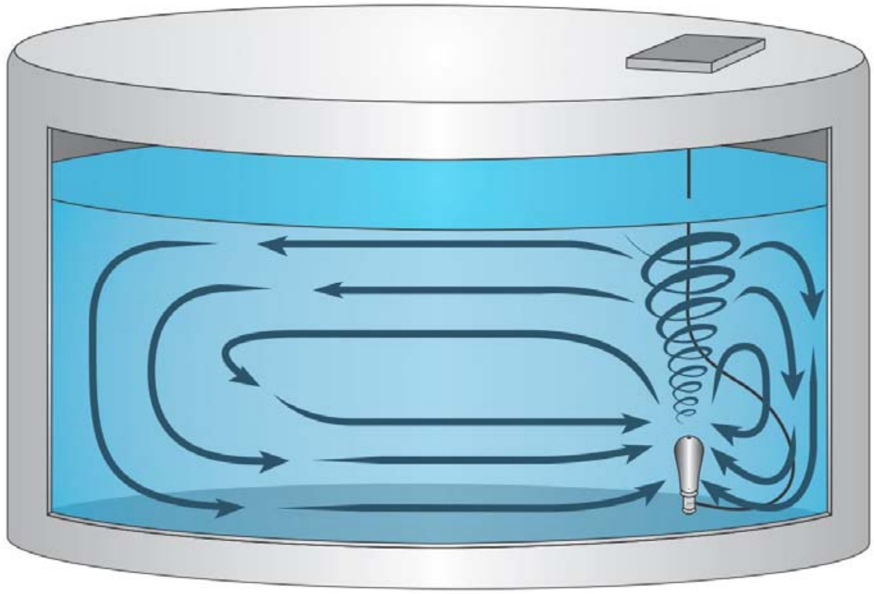
Search

PAX Water Mixer (PWM100)

Active vortex mixer for small tanks

The PAX Water Mixer (PWM100) is an active vortex mixer for small water storage tanks. Patented PAX technology provides the most powerful mixing for small tanks to thoroughly circulate the entire tank volume. The mixer features a self-install design that translates into significant cost and labor savings, making it an economical purchase for small utilities with a limited budget. Read more

How it Works



The PWM100 uses a vortex nozzle to vigorously circulate the tank volume to eliminate thermal stratification, prevent ice formation, reduce residual loss and lower disinfection byproducts. The mixer can be installed by lowering it into the tank from the hatch and self-rights once it reaches the tank floor, even on a sloped surface. Read more

Features

- Most powerful mixer in its class
- Easy install, self-righting design
- NSF/ANSI Standard 61 and UL certified
- 3-year warranty

Specifications

- Power Supply Requirement: 120 VAC, 60 Hz, GFCI-protected, 20 amp circuit
- Motor Type: 115 VAC, 60 Hz, water-filled, water-lubricated
- Nominal Power Draw: 1.15 kVA (670 watts)
- Footprint (Diameter): 10" (25.4 cm)
- Height: 30" (76.2 cm)
- Material (Housing): 316 stainless steel
- Weight: 40 lbs (18.1 kg)

- PAX Water Technologies Inc.
- 860 Harbour Way South
- Richmond, CA 94804
- PHONE 866.729.6493
- EMAIL info@paxwater.com

- Technology
- Why Mix
- Our Advantage
- Biomimicry

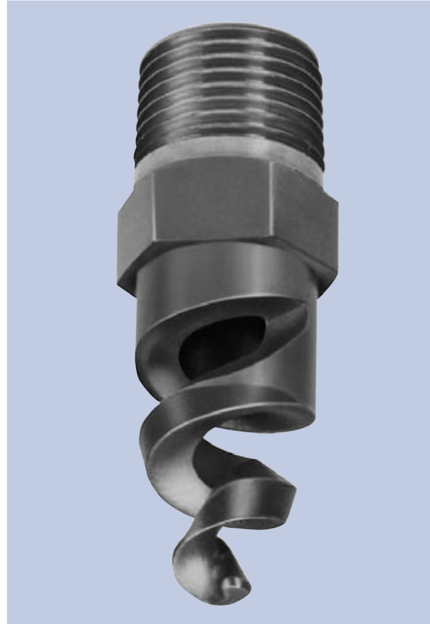
TF

Wide Range of Flows and Angles

DESIGN FEATURES
- The original spiral nozzle invented by BETE and continuously improved!
- High energy efficiency
- One-piece/no internal parts
- Clog-resistant performance
- High discharge velocity
- Male connection standard; female connection available by special order

SPRAY CHARACTERISTICS
- Wide range of flow rates and spray angles
- Fine atomization

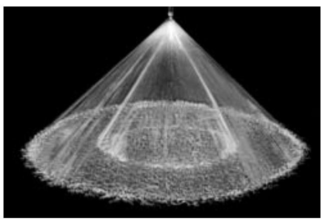
Spray patterns: Full Cone.
For Hollow Cone, see page 45
Spray angles: 50° to 180°
Flow rates: 0.5 to 3320 gpm
(Higher flow rates available)



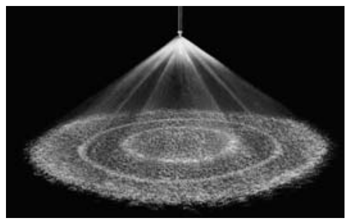
60°, 90°, 120° Metal

Available with FM approval: N series (page 102), 1/4" TF8 NN, FCN in brass, 1/2" TF24-150 in multiple materials

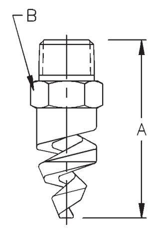
Full Cone 60° (NN)



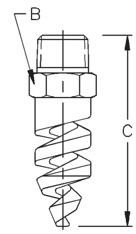
Full Cone 90° (FCN)



Full Cone 150°/170°



90°, 120°



150°, 170°

Dimensions are approximate. Check with BETE for critical dimension applications.

TF Full Cone Flow Rates and Dimensions
Full Cone, 60° (NN), 90° (FCN or FFCN), 120° (FC or FFC), 150° and 170° Spray Angles, 1/8" to 4" Pipe Sizes

Male Pipe Size	Nozzle Number	Available Spray Angles 60° 90° 120° 150° 170°	K Factor	GALLONS PER MINUTE @ PSI: 5 PSI	10 PSI	20 PSI	30 PSI	40 PSI	50 PSI	60 PSI	80 PSI (PTFE not recommended above red line)	100 PSI	200 PSI (Metal Only above green line)	400 PSI	Approx. (in.) Orif. Dia.	Free Pass. Dia.	Dim. (in.) for Metal Only* A**	B	C	Wt. (oz.) 60° 90° 120° Metal	Plas.
1/8	TF6	60° 90° 120° 150° 170°	0.221	0.495	0.70	0.99	1.21	**1.40**	1.57	1.71	1.98	2.21	3.13	4.43	0.09	0.09	1.69	0.56	1.69	1.00	0.20
	TF8	60° 90° 120° 150° 170°	0.411	0.919	1.30	1.84	2.25	**2.60**	2.91	3.18	3.68	4.11	5.81	8.22	0.13	0.13	1.69	0.56	2.19		
1/4	TF6	60° 90° 120° 150° 170°	0.221	0.495	0.70	0.99	1.21	**1.40**	1.57	1.71	1.98	2.21	3.13	4.43	0.09	0.09	1.88	0.56	1.88	1.25	0.20
	TF8	60° 90° 120° 150° 170°	0.411	0.919	1.30	1.84	2.25	**2.60**	2.91	3.18	3.68	4.11	5.81	8.22	0.13	0.13	1.88	0.56	2.38		
	TF10	60° 90° 120° 150° 170°	0.632	1.41	2.00	2.83	3.46	**4.00**	4.47	4.90	5.66	6.32	8.94	12.6	0.16	0.13	1.88	0.56	2.38		
3/8	TF6	60° 90° 120°	0.221	0.495	0.70	0.99	1.21	**1.40**	1.57	1.71	1.98	2.21	3.13	4.43	0.09	0.09	1.88	0.69	2.38	1.63	0.25
	TF8	60° 90° 120°	0.411	0.919	1.30	1.84	2.25	**2.60**	2.91	3.18	3.68	4.11	5.81	8.22	0.13	0.13					
	TF10	60° 90° 120°	0.632	1.41	2.00	2.83	3.46	**4.00**	4.47	4.90	5.66	6.32	8.94	12.6	0.16	0.13					
	TF12	60° 90° 120° 150° 170°	0.949	2.12	3.00	4.24	5.20	**6.00**	6.71	7.35	8.49	9.49	13.4	19.0	0.19	0.13					
	TF14	60° 90° 120° 150° 170°	1.28	2.86	4.05	5.73	7.01	**8.10**	9.06	9.92	11.5	12.8	18.1	25.6	0.22	0.13					
	TF16	60° 90° 120° 150° 170°	1.68	3.75	5.30	7.50	9.18	**10.6**	11.9	13.0	15.0	16.8	23.7	33.5	0.25	0.13					
	TF20	60° 90° 120° 150° 170°	2.61	5.83	8.25	11.7	14.3	**16.5**	18.4	20.2	23.3	26.1	36.9	52.2	0.31	0.13					
1/2	TF24	60° 90° 120° 150° 170°	3.81	8.52	12.1	17.0	20.9	**24.1**	26.9	29.5	34.1	38.1	53.9	76.2	0.38	0.19	2.50	0.88	3.06	3.00	0.50
	TF28	60° 90° 120° 150° 170°	5.22	11.7	16.5	23.3	28.6	**33.0**	36.9	40.4	46.7	52.2	73.8	104	0.44	0.19					
3/4	TF32	60° 90° 120° 150° 170°	6.64	14.8	21.0	29.7	36.4	**42.0**	47.0	51.4	59.4	66.4	93.9	133	0.50	0.19	2.75	1.13	3.50	5.50	0.88
1	TF40	60° 90° 120° 150° 170°	10.6	23.7	33.5	47.4	58.0	**67.0**	74.9	82.1	94.8	106	150	212	0.63	0.25	3.63	1.38	4.38	8.50	2.50
	TF48	60° 90° 120° 150° 170°	15.0	33.6	47.5	67.2	82.3	**95.0**	106	116	134	150	212	300	0.75	0.25					
1 1/2	TF56	60° 90° 120° 150° 170°	20.4	45.6	64.5	91.2	112	**129**	144	158	182	204	288	408	0.88	0.31	4.38	2.00	5.38	22.0	4.25
	TF64	60° 90° 120° 150° 170°	26.7	59.7	84.5	120	146	**169**	189	207	239	267	378	534	1.00	0.31			5.38		
	TF72	60° 90° 120° 150° 170°	30.4	67.9	96.0	136	166	**192**	215	235	272	304	429	607	1.13	0.31			5.63		
2	TF88	60° 90° 120° 150° 170°	44.3	99.0	140	**198**	242	280	313	343	396	443	626	885	1.38	0.44	5.63	2.50	5.88	46.0	8.00
	TF96 [1]	60° 90° 120° 150° 170°	55.9	125	177	**250**	306	354	395	433	500	559	791	1120	1.50	0.44	6.88	2.50	7.00	54.0	9.00
3	TF112 [1]	60° 90° 120° 150° 170°	81.0	181	256	**362**	443	512	572	627	724	810	1150	1620	1.75	0.56	8.63	3.50	9.25	114	20.0
	TF128 [1]	60° 90° 120° 150° 170°	107	239	339	**480**	588	679	759	831	960	1070	1510	2150	2.00	0.56					
4	TF160 [1]	60° 90° 120°	166	371	**525**	742	909	1050	1170	1290	1480	1660	2350	3320	2.50	0.63	10.1	4.50		169	27.0

Flow Rate (GPM) = K $\sqrt{PSI}$ *Dimensions are for bar stock, cast sizes may vary.   **60° nozzles slightly longer, consult BETE.   [1] Three turn nozzles

Standard Materials: Brass, 316 Stainless Steel, PVC, Polypropylene, Cobalt Alloy 6, and PTFE (Poly. not available for TF6 thru TF10).

Spray angle performance varies with pressure. Contact BETE for specific data on critical applications.

***TO ORDER:** specify pipe size, connection type, nozzle number, spray angle, and material.*

Home / Products / Electric Meters (KWh Meters) / **Basic kWh Meter 100A 120/240-volt, 3-wire, 60Hz EKM-25IDS**

Click on image to zoom

Basic kWh Meter 100A 120/240-volt, 3-wire, 60Hz EKM-25IDS

Be the first to review this product

Availability: In stock

$90.00

Qty: 0 **Add to Cart** Add to Wishlist

-OR-

Check out with PayPal
The safer, easier way to pay

Details

Voltage: **120/240 volts 3-Wire**

Amperage: **up to 100 amps**

Type: **Pass-Through, Single-Phase, 60Hz**

Data: **Pulse Output - 800 pulses per kWh**

Model: **EKM-25IDS**

This is a very popular product if you are metering your North American household power and you want a simple read off the face kWh meter.

State-of-the-art, fully solid-state kWh meter with 800 pulse per kWh pulse output

1% accuracy, LCD readout in hundredths of a kWh, to 99999.99 kWh. No conversion factor or multiplier. Basic Meter 120/240V 3-wire, 100A version, Neutral bypasses the meter

Compact, very easy to install design. Simple DIN-rail mounting. Wires pass through 3/8+" diameter tubes in the meter body --Will accept some (but not all) #2AWG insulated wire. The only electrical connection is made by 2 small screws which penetrate the wire insulation and pick up power--less than 1 watt--to power the meter.

Non-resettable LCD display. Usage data is maintained through power outages.

Single-phase energy meter, 100A 120/240-volt, 3-wire, 60Hz

Standard North American household current. Most commonly a white neutral, a black hot and a red hot wire, 200V to 252V between the hots, 110V to 126V either hot to neutral. Very voltage tolerant--the meters will tolerate voltages from 168 V to 312V hot to hot, 84V to 156V hot to neutral !! This meter will not work on a 120 volt 2 wire system, for this you will need our EKM-15IDS or EKM-15E meter.

EKM-25IDS Spec Sheet: EKM-25IDS Spec Sheet

Email to a Friend

Techical Specifications:

- 120/240V Single Phase, pass-through kWh meter
- Rated Voltage: 120/240 volts
- Rated current: 5(100)A
- Works with wires up to 3/8" in diameter
- Pulse output impulse constant: 800imp/kWh
- Range of allowable environmental conditions: Pollution Degree 2, Measurement Category III, Altitude rating 2000 meters max. Maximim Temperature Range: -30 Deg. C to 70 Deg. C.
- The equipment is protected throughout by double insulation as indicated by this symbol: ▣
- Accuracy Class: 1 *(Fig 3)*
- Rated Frequency: 50Hz/60Hz
- Creep: Logical design of anti-creep
- Start current: 0.4% Ib. (1.0)
- Power consumption: ≲1W (when 220V, 20A)
- Tamper Detection Class 1.
- Weight: 0.32kg
- Outside dimensions: 78x100x65mm *(Fig 1)*

Safety Precautions:

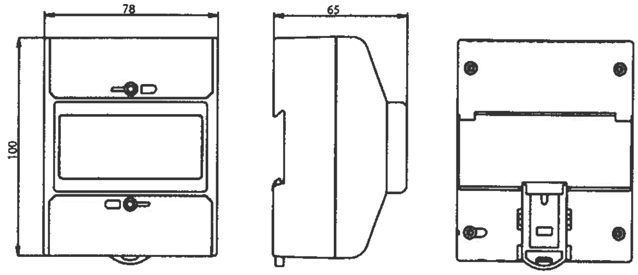
- Meter should be installed by a qualified electrician.
- Turn off all power supplying the equipment before preforming any intallation or service. Use a volt meter to confirm power is off.
- Use of this device inconsistent with this manual can cause permanent damage to the unit and/or serious harm to the installer or operator.

Tools/Materials List:

- Volt meter
- Small standard screwdriver
- DIN-Rail
- UL Listed Type 4 Enclosure (with appropriately rated conduit and fittings) is required if meter will be installed outdoors

Functions:

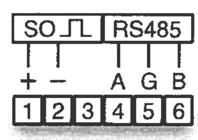
- Long-term active electricity measuring without adjustment.
- Meets IEC 62053-21 and IEC 62052-11 standards (static AC active meter)
- With RS485 communication, index in accordance with IEC 62056-21(A mode), which focuses on convenient intelligent energy management.



(Fig 1)

Installation Instructions:

1. Use a volt meter to confirm that you have 240 volts between L1 and L2. This meter will not function correctly unless this is the case. For 120V systems, use our any of the EKM-Omnimeter meter models.
2. Disconnect or switch power off before attempting to install, connect, disconnect, or service the meter. ALL POWER MUST BE TURNED OFF!
3. IMPORTANT: Distinguish and then identify the 2 hot Lines and the neutral line. Label all 3: L1, L2, N.
4. Once the power has been turned off, pass line 1 and line 2 through the two holes in the meter. (for a retrofit installation this may first require diconnecting the ends of L1 and L2 from a breaker or junction box)
5. Once the wires are through the meter, the ends should be reconnected in their orignal positions. On the meter, tighten down the tap screws for each line that passes through the meter. The tap screw will give the meter its voltage reference as well as power the meter once the power is turned back on.
6. Mount the meter using 35mm DIN Rail in a protected indoor location. If installing outdoors, a UL Listed Type 4 Enclosure is required.
7. Once the above steps are completed, and you are ready, you can turn the power back on and begin to read your meter.



(Fig 2)

RS-485 and Pulse Output*(Fig 2)*:

- Terminal 4 (A) connects to RS-485+ or T+ on the RS-485 network. Terminal 6 (B) connects to RS-485- or T-. Terminal 5 (G) is used for the RS-485 network (signal) ground if needed. Observe proper RS-485 network topology. Twisted pair wiring is recommended. Shielded twisted pair may be benificial in electrically noisy environments or for very long runs. RS-485 supports up to 256 devices on up to 4000 feet wire. Terminating resistors may be beneficial.
- Terminals 1 and 2 are for pulse output. Pulse rate: 800 Impulse/kWh. Polarity sensitive. Maximum 27VDC, 27mA.

Load current	Power factor COSθ	Basic error %		
		Class 0.5	Class 1	Class 2
0.05Ib	1.0	±1.0	±1.5	±2.5
0.1Ib~Imax	1.0	±0.5	±1.0	±2.0
0.1Ib	0.5(L)	±1.0	±1.5	±2.5
	0.8(C)	±1.0	±1.5	—
0.2Ib~Imax	0.5(L)	±0.5	±1.0	±2.0
	0.8(C)	±0.5	±1.0	—

(Fig 3)

Working Principle:
When the meter is working, the energy consumed by the user is transformed into voltage and current signals, which are sampled by sample circuits. A pulse signal is then produced by a specialized IC. The Pulse signal is directly proportional to power consumption. The MCU records and stores the corresponding energy use. The LCD screen displays the energy use. Recorded information and data can be transferred using the RS485 interface.

Data:
The LCD display shows seven pieces of data: total electricity consumed(kWh), reverse kWh, voltage, current, total power, L1 COSθ, and L2 COSθ(power factor). Every five seconds the LCD screen will display a new piece of data. The meter also provides max demand(kW) data and the demand period can be set to one of three intervals: 15minutes, 30 minutes, or 60 minutes. The max demand can be reset to zero in software over RS485. The meter has four time-of-use tariffs(T1, T2, T3, T4) to calculate the power during different time periods, and it can set up to four time periods per day, and specify the number of the tarrif for that period(from T1 to T4). The meter time can be set using the RS485 interface. By design the kWh cannot be reset. The meter will go at least 10 years without power and still keep its kWh readings. In other words, the memory will not be erased if there is no power.

Transport and Handling:
The meter should be handled with care, as there are precision components inside that could break and/or cause faulty readings should the meter become damaged. The process of transportation, handling, and installation should be done according to the transportation and storage rule of GB/T15464≤1995. Keep the meter in the original packaging when stored. The storage temperature range should be 0–40ºC. The relative humidity should be 85%. There should be no toxic chemicals present and no corrosive substances or gases in the air. The meters should be stacked on a platform no more than ten units high.

Warranty:
Within two years from the date of sale, and on the condition that the user abide by the specifications and installation instructions list here, and the sealing is kept completely intact. If the meter does not correspond with the rule of the enterprise standard, the meter shall be repaired free or replaced.

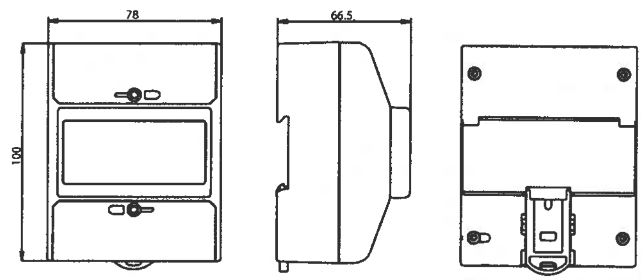
- Nominal Voltage Ranges:
  120V to 480V, 2-wire, Single-phase, One Line & Neutral
  120V to 480V, 3-wire, Single-phase, 2 Lines & Neutral
  120V to 415V, 3-wire, 3-phase, 3 Lines, No Neutral
  120V to 480V, 4-wire, 3-phase, 3 Lines and Neutral
- Range of allowable environmental conditions: Pollution Degree 2, Measurement Category III, Altitude rating 2000 meters max. Maximum Temperature Range: -30 Deg. C to 70 Deg. C. Tamper Detection Class 1.
- The equipment is protected throughout by double insulation as indicated by this symbol: ▣
- Accuracy Class 0.5
- Rated Frequency: 50Hz/60Hz
- Red LED on the meter face flashes 800 times/kWh. 1 flash = 1.25Wh.
- Received California Type Approval for revenue grade metering

Safety Precautions:
- Meter should be installed by a qualified electrician.
- Turn off all power supplying the equipment before preforming any wiring. Use a properly rated volt meter to confirm power is off.
- Use of this device inconsistent with this manual can cause permanent damage to the unit and/or serious harm to the operator.

Tools/Materials List:
- Volt meter
- Small standard screwdriver
- Wire stripper
- DIN-Rail
- 16-22 AWG stranded copper wire
- Inline fuse holder with maximum 1Amp fuse
- Use a Type 4 Enclosure (with appropriate conduit and fittings) if meter will be installed outdoors

Installation Instructions

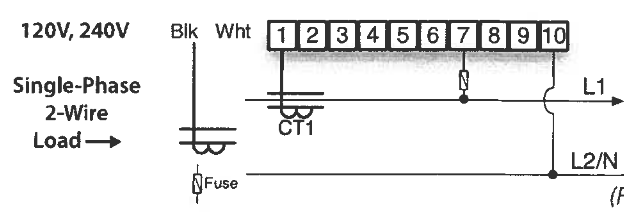
For All Systems:
1. Disconnect or switch power off before attempting to install, connect, disconnect or service the meter or the external current transformers (CTs). ALL POWER MUST BE DISCONNECTED!
2. Mount the meter using 35mm DIN Rail in a protected indoor location. If installing outdoors, a UL Listed Type 4 Enclosure is required.
3. IMPORTANT: Distinguish and then identify the Neutral and the Line(s) ('hot' wire(s), usually black or red). Label the Neutral and then, depending on your electrical system, assign labels as described below.
4. Tightening torque of terminals:
   Terminals 7,8,9 (Line) and 10 (Neutral): 10.6 to 13.2 in-lb. (1.2 to 1.5 Nm)
   All other terminals: 4.4 to 5.3 in-lb. (0.5 to 0.6 Nm)



Load current	Power factor COSθ	Basic error %	
		Class 0.5	Class 1
0.05Ib	1.0	±1.0	±1.5
0.1Ib~Imax	1.0	±0.5	±1.0
0.1Ib	0.5(L)	±1.0	±1.5
	0.8(C)	±1.0	±1.5
0.2Ib~Imax	0.5(L)	±0.5	±1.0
	0.8(C)	±0.5	±1.0

(Fig 1)

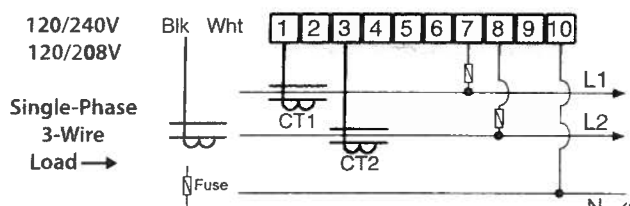
120V, 2-Wire, Single Phase:
1. Label Line 1 as L1.
2. Fit CT1 around L1. Make sure the arrow is facing towards the load (in the direction of flow). *(Fig 2)*
3. Black CT wire connects to Port 1 on the Omnimeter. White CT wire connects to Port 2. *(Fig 2)*
4. With split core CTs, clamp together until the buttons pop out. Use a zip tie to ensure the CT remains securely closed.
5. To power the meter and get a voltage reference: Use a maximum 1.0 Amp inline fuse on L1. Connect one fuse holder pigtail to the breaker, lug or an appropriate line-tap device, and connect the other pigtail to 16-22 AWG UL rated stranded copper wire for connection to the meter.
6. L1 connects to Port 7 on the Omnimeter, Neutral to Port 10. *(Fig 2)*
7. Once the meter is properly mounted to the DIN Rail or enclosure and all wiring is completed, with terminal block covers installed, power can be turned back on.
8. Meter will then begin cycling through meter values. For details go to: *http://documents.ekmmetering.com/EKM_Metering_LCD_Display_Value_Reading.pdf*
9. A video of proper install of a 120V system can be found here: *http://www.youtube.com/watch?v=ky9sgr1LTMk*



(Fig 2)

120/240V, 120/208V, Single Phase, 3-Wire:
1. Label L1 and L2. (Arbitrarily assign labels.)
2. You will be using 2 CTs for this install. Label them CT1 and CT2.
3. Fit CT1 around L1. Make sure the arrow is facing towards the load (in the direction of flow).
4. Fit CT2 around L2.

5. Black wire from CT1 connects to Port 1 on the Omnimeter. White wire from CT1 connects to Port 2. *(Fig3)*
6. Black wire from CT2 connects to Port 3. White wire from CT2 connects to Port 4. *(Fig 3)*
7. With split core CTs, clamp together until buttons pop out. Use a zip tie to ensure the CTs remain securely closed.
8. To power the meter and get a voltage reference: Use a maximum 1 Amp inline fuse on L1 and L2. Connect one fuse holder pigtail to the breaker, lug or an appropriate line-tap device, connect the other pigtail to 16-22 AWG UL rated stranded copper wire.
9. Tap into L1 at the breaker panel, with small stranded copper wire. This L1 tap connects to Port 7 on the Omnimeter. *(Fig 3)*
10. Tap into L2 at the breaker panel with small stranded copper wire. This L2 tap connects to Port 8 on the Omnimeter. *(Fig 3)*
11. Neutral connects to Port 10.
12. Once the meter is properly mounted to the DIN Rail or enclosure and all wiring is completed, with terminal block covers installed, power can be turned back on.
13. Meter will then begin cycling through meter values. For details go to: *http://documents.ekmmetering.com/EKM_Metering_LCD_Display_Value_Reading.pdf*
14. A video of a proper install of a 120V/240V system can be found here: *http://www.youtube.com/watch?v=ky9sgr1LTMk*

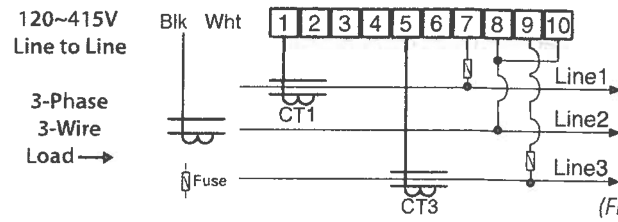


(Fig 3)

120V-415V, 3-Phase, 3-Wire:

1. Label L1, L2 and L3. (Arbitrarily assign labels.)
2. You will be using 2 CTs for this install. Label them CT1 and CT3.
3. Fit CT1 around L1. Make sure the arrow is facing towards the load (in the direction of flow).
4. Fit CT3 around L3.
5. Black wire from CT1 connects to Port 1 on the Omnimeter. White wire from CT1 connects to Port 2. *(Fig 4)*
6. Black wire from CT3 connects to Port 5 on the Omnimeter. White wire from CT3 connects to Port 6. *(Fig 4)*
7. With split core CTs, clamp together until buttons pop out. Use a zip tie to ensure the CTs remain securely closed.
8. To protect the meter and wiring, use a maximum 1.0 Amp inline fuse on each line.
9. To power the meter and get a voltage reference:
   Tap into L1 at the breaker panel. Connect one fuse holder pigtail to the breaker, lug or an appropriate line-tap device, and connect the other pigtail to16-22 AWG UL rated stranded copper wire for connection to the meter. This L1 tap connects to Port 7 on the Omnimeter. Tap into L2 and L3 and repeat the connection process. L2 tap connects to Port 8. Be sure to add a jumper to Port 10. *(Fig 4)* L3 tap connects to Port 9.
10. Once the meter is properly mounted to the DIN Rail or enclosure and all wiring is completed, with terminal block covers installed, power can be turned back on.
11. Meter will then begin cycling through meter values. For details, go to: *http://documents.ekmmetering.com/EKM_Metering_LCD_Display_Value_Reading.pdf*
12. A video of a proper 120V-208V, 3-Wire, 3-Phase system can be found here: *http://www.youtube.com/watch?NR=1&v=upNgFNV6EDM*

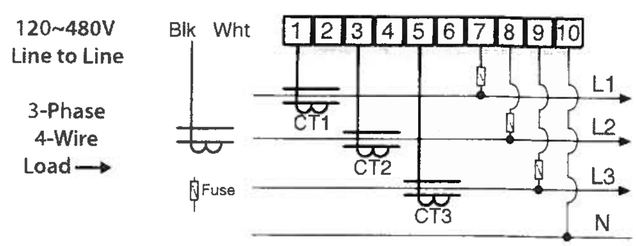
Note: 3-phase, 3-wire, 480v electrical systems cannot be metered with this meter model. For 3-phase, 480v electrical systems, the Omnimeter must have a true neutral in order to meter accurately and avoid being damaged by high voltages. In cases where there is no neutral on the system being metered, it may be possible to run a neutral from the transformer or electrical panel, to the Omnimeter. Again, this meter must have a true neutral in order to meter 3-phase, 480 volt, electrical systems. This would make it a 3-phase 4-wire system and would also require a 3rd current transformer.



(Fig 4)

120V-480V, 3-Phase, 4-Wire:

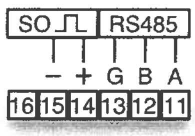
1. Label L1, L2 and L3. (Arbitrarily assign labels.)
2. You will be using 3 CTs for this install. Label them CT1, CT2 and CT3.
3. Fit CT1 around L1 Make sure the arrow is facing towards the load (in the direction of flow).
4. Fit CT2 around L2.
5. Fit CT3 around L3.
6. Black wire from CT1 connects to Port 1 on the Omnimeter. White wire from CT1 connects to Port 2. *(Fig 5)*
7. Black wire from CT2 connects to Port 3 on the Omnimeter. White wire from CT2 connects to Port 4. *(Fig 5)*
8. Black wire from CT3 connects to Port 5 on the Omnimeter. White wire from CT3 connects to Port 6. *(Fig 5)*
9. With split core CTs, clamp together until buttons pop out. Use a zip tie to ensure the CTs remain securely closed.
10. Use a max 1.0 Amp inline fuse on each line to protect the meter.
11. To power the meter and get a voltage reference: Tap into L1 at the breaker panel. Connect one fuse holder pigtail to the breaker, lug or an appropriate line-tap device, and connect the other pigtail to 16-22 AWG UL rated stranded copper wire for connection to the meter. L1 connects to Port 7. Tap into L2 and L3 and repeat the connection process. L2 connects to Port 8. L3 connects to Port 9. Neutral connects to Port 10. *(Fig 5)*
12. Once the meter is properly mounted to the DIN Rail or enclosure and all wiring is completed, with terminal block covers installed, power can be turned back on.
13. Meter will then begin cycling through meter values. For details, go to: *http://documents.ekmmetering.com/EKM_Metering_LCD_Display_Value_Reading.pdf*
14. A video of proper install of a 120V-208V, 3-Phase, 4-Wire system can be found here: http://www.youtube.com/watch?v=DeKiZddR0K8



(Fig 5)

RS-485 and Pulse Output:

- Terminal 11 (A) connects to RS-485+ or T+ on the RS-485 network. Terminal 12 (B) connects to RS-485- or T-. Terminal 13 (G) is used for the RS-485 network (signal) ground if needed. Observe proper RS-485 network topology. Twisted pair wiring is recommended. Shielded twisted pair may be beneficial in electrically noisy environments or for very long runs. RS-485 supports up to 256 devices on up to 4000 feet wire. Terminating resistors may be beneficial.
- Terminals 14 and 15 are for pulse output. Pulse rate: 800 Impulse/kWh when set to 200A. Polarity sensitive. Maximum 27VDC, 27mA.
- Red LED on the meter face flashes 800 times/kWh(1 flash = 1.25Wh) when set to 200A.



(Fig 6)

CT Ratio	Impulse Constant
100/26.6	1600
200/26.6	800
400/26.6	400
800/26.6	200
1500/26.6	106.67
3000/26.6	53.33
5000/26.6	32

(Fig 7)

All EKM meters, including the Omnimeter I v.3, have a Pulse Output. The Pulse Output pulses at a rate of 800 pulses per kilowatt hour when set to use 200 amp current transformers. This is the same rate that the red LED flashes on the meter face — 800 times/kWh. These are unpowered electronic dry contact pulses that can be counted by standard electronic pulse counters. Pulse counters can be located up to 200 feet away from the Omnimeter.

***Note:** Some Omnimeter I v.3 meters have a slightly different configuration for the pulse output terminals. These meters are identifiable by a sticker on the meter case showing the different configuration. In the case of these meters, please follow the direction of the sticker, not of this spec sheet.

Working Principle:
When the meter is working, the energy consumed by the user is transformed into voltage and current signals, which are sampled by sample circuits. A pulse signal is then produced by a specialized IC. The Pulse signal is directly proportional to power consumption. The MCU records and stores the corresponding energy use. The LCD screen displays the energy use. Recorded information and data can be transferred using the RS485 interface.

Data:
The LCD display shows 15 pieces of data: total energy consumption(kWh), reverse kWh, voltage L1,voltage L2,voltage L3, current(Amps) L1, current L2, current L3, power(watts) L1, power L2, power L3, total power(watts), COSθ(power factor) L1, COSθ L2, and COSθ L3. Every five seconds the LCD screen will display a new piece of data. The meter also provides max demand(kW) data and the demand period can be set to one of three intervals: 15minutes, 30 minutes, or 60 minutes. The max demand can be reset to zero in software over RS485. The meter has four time-of-use tariffs(T1, T2, T3, T4) to calculate the power during different time periods, and it can set up to four time periods per day, and specify the number of the tariff for that period(from T1 to T4). The meter time can be set using the RS485 interface. By design the kWh cannot be reset. The meter will go at least 30 years without power and still keep its kWh readings. In other words, the memory will not be erased if there is no power. See Figure 8 for meter display values:

#	LCD Display Data	#	LCD Display Data	#	LCD Display Data
01	Total kWh (forward + reverse)	06	Amps L1	11	Watts L3
02	Reverse kWh	07	Amps L2	12	Watts Total
03	Volts L1 (Line 1)	08	Amps L3	13	CosΘ L1 (Power Factor)
04	Volts L2	09	Watts L1	14	CosΘ L2
05	Volts L3	10	Watts L2	15	CosΘ L3

(Fig 8)

Transport and Handling:
The meter should be handled with care, as there are precision components inside that could break and/or cause faulty readings should the meter become damaged. The process of transportation, handling, and installation should be done according to the transportation and storage rule of GB/T15464-1995. Keep the meter in the original packaging when stored. The storage temperature range should be 0–40ºC. The relative humidity should be ≤85%. There should be no toxic chemicals present and no corrosive substances or gases in the air. The meters should be stacked on a platform no more than ten units high.

Warranty:
Within two years from the date of sale, and on the condition that the user abide by the specifications and installation instructions listed here, and the sealing is kept completely intact. If the meter does not correspond with the rule of the enterprise standard, the meter shall be repaired free or replaced.