TROJAN UV
WATER CONFIDENCE™

Chobani, Twin Fall, Idaho

TrojanUVFlex100™ - Advanced Oxidation System

Performance Test Report

September 8, 2023

EXHIBIT 15

Contents

1 INTRODUCTION/BACKGROUND

Haskell has installed a UV advanced oxidation system at the Chobani factory in Twin Fall, Idaho for the treatment of 1,4-dioxane and NDMA. The current duty system consists of two trains (1 duty+1 standby) of TrojanUVFlex100™ UV Advanced Oxidation Process (UV-AOP) chambers, along with a hydrogen peroxide (H_2O_2) dosing system. The chamber contains 2 lamp sections, and each section is comprised of 16-500 W Solo UV lamps.

Trojan Technologies, along with Haskell and Brown & Caldwell, completed on-site performance testing of the UV-AOP system from June 26-30, 2023. This report describes the methods, procedures and test conditions used during the performance testing and summarizes the overall test results based on the analytical data from a third-party laboratory.

2 OBJECTIVES

The primary objective of TrojanUVFlex100 ™ UV-AOP system performance testing was to verify that the installed UV system could meet the treatment criteria at the design operating conditions, as summarized in Table 2-1. A secondary objective was to obtain data to demonstrate the response of the system's automatic control program over various water UV transmittance (UVT) values and flow rates.

Table 2-1: Summary of UV-AOP Design Conditions.

	Current
Peak Design Total Flow, GPM	278
Minimum UVT at 254 nm, %	96
1,4-Dioxane Log_{10} Reduction	≥0.5
NDMA Log_{10} Reduction	≥1.0
Max. Hydrogen Peroxide Conc. (mg/L)	6.5
Max. Nitrate (mg/L as N)	0.19
Max. Nitrite (mg/L as N)	0.08

3 UV-OXIDATION FUNDAMENTALS

3.1 TREATMENT MECHANISMS

UV light-based advanced oxidation processes (UV-AOPs) rely upon the simultaneous mechanisms of direct UV photolysis and hydroxyl radical-induced oxidation to degrade chemical contaminants in water. UV-photolysis is the process by which chemical bonds in the contaminant structures are broken by the energy associated with the UV light absorbed by those compounds. UV-photolysis does *not* require the addition of H_2O_2. A UV-AOP process in the presence of an oxidant (*e.g.* H_2O_2) relies on the *in-situ* generation of hydroxyl radicals (•OH) through the UV-photolysis of H_2O_2 which is dosed to the water, and the subsequent oxidation of chemical contaminants initiated by hydroxyl radicals.

Hydrogen peroxide is commercially available as aqueous solutions of varying strength. It is a relatively weak absorber of UV light having a molar absorption coefficient at 254 nm of 19.6 $L\ mol^{-1}\ cm^{-1}$. Nevertheless, the quantum yield of hydroxyl radical formation from hydrogen peroxide UV photolysis approaches unity. Therefore, the UV/H_2O_2 process is one of the most efficient advanced oxidation processes.

Hydroxyl radicals are extremely reactive, short lived and unselective transient species. Due to their high reactivity in natural waters, especially in the presence of naturally occurring organic matter (NOM) and alkalinity, these radicals will instantly react with the water constituents and do not exist beyond the boundaries of the UV reactor volume.

Hydroxyl radicals can oxidize organic and inorganic compounds by various types of reactions, comprising electron transfer, hydrogen abstraction and electrophilic addition reactions. In UV oxidation treatment processes, the yield of hydroxyl radicals is optimized based on the H_2O_2 required for a given contaminant treatment level for a given water quality, flow and UV system operating conditions.

3.2 WATER QUALITY PARAMETERS

3.2.1 UV Transmittance

UV transmittance (UVT) is the spectral radiant power (P_λ) transmitted through a medium (*e.g.* water sample) across a particular pathlength (l) divided by the spectral radiant power incident on the sample (P_λ^0). UVT is measured using a UV spectrophotometer. Reagent grade water is used to zero the instrument (*i.e.*, UVT = 100%). UV absorbance (A) at a given wavelength (λ) correlates to the amount of light absorbed by a solution over a given pathlength (l). UVT and UV absorbance are related through the following equation:

$$UVT(\lambda, \%) = 10^{-A(\lambda)} \times 100$$

The typical cell pathlength is 1 cm and both transmittance and absorbance values are commonly reported per cm. A key reference wavelength and one at which UVT is often reported is 254 nm, which is also the radiation emitted from the excited state of mercury atoms in the low-pressure mercury vapor arc lamps. UV Transmittance depends on the concentration of UV light-absorbing compounds and particles (which also scatter the light) present in the water matrix. The higher the water background UV absorption, the lower is the UV light availability to H_2O_2 for hydroxyl radical generation and to organic contaminants for the direct UV photolysis. The UV transmittance is one of the key water quality parameters used in the UV equipment sizing for a given application.

3.2.2 Hydroxyl Radical Scavenging Demand

While the desired reactions in UV oxidation processes are between photo-generated hydroxyl radicals and contaminant molecules, the non-selective nature and high reactivity of hydroxyl radicals result in reactions between these species and various organic and inorganic water constituents, which always occur at much higher concentrations than the target micropollutants. Examples of such hydroxyl radical scavengers are the dissolved natural organic matter (NOM), carbonate and/or bicarbonate ions, iron and manganese ions, etc. Hydrogen peroxide itself reacts with hydroxyl radical; thus, the kinetic model used to determine the UV/H_2O_2 process conditions and to size the UV equipment optimizes the H_2O_2 concentration required to generate the highest •OH yield, while affecting a minimum •OH demand. The •OH water background demand has a negative impact on the steady-state concentration of hydroxyl radicals in the water. Since the rate of contaminant degradation is proportional to the steady-state concentration of hydroxyl radicals, these hydroxyl radical scavenging reactions reduce the rate of contaminant degradation. The •OH water background demand (also known as 'scavenging term'; $\sum k_s[S]$ or S.T.) is water matrix-specific and must be determined experimentally through a properly developed and validated method. Trojan routinely determines the scavenging demand of water samples at its laboratory in London, Ontario. The •OH water background demand is another key water quality parameter used by the kinetic model for sizing the UV equipment for a given UV/H_2O_2 AOP application.

In principle, the method for the •OH water background demand relies on the competition kinetics for the hydroxyl radicals between the water matrix constituents and a probe compound which is added to the sample (Zhou and Mopper, 1996; Rosenfeldt and Linden, 2007; Rosenfeldt, 2010; Lee and von Gunten, 2010; Keen *et al.*, 2014; Kwon *et al.*, 2014; Gerrity *et al.*, 2016; Wang *et al.*, 2020). The most commonly used probe compound is para-chlorobenzoic acid (pCBA) providing its well characterized rate constant for the OH radical reaction (5.0×10^9 M^{-1} s^{-1}; Buxton *et al.*, 1988) and known quantum yield and molar absorption coefficient at 254 nm. Upon reviewing the literature published over the years and extensive use of pCBA for quantification of OH radical steady state concentration, Trojan adopted and used pCBA as a probe for the •OH water background demand determination in samples collected from water treatment plants in the past.

In a recent article, Kim *et al.* (2021) reported for the first time in the literature on a potential unidentified reaction of pCBA in the UV/H_2O_2 process in addition to the known •OH- and direct photolysis-based degradation. The authors examined several chemical compounds of various structures as potential •OH chemical probes, among which, p-CBA. The experimental data indicated that para-substituted benzoic acids, in particular, are vulnerable to attack by an unknown reactive species, leading to false quantification of •OH. As a result, the •OH water background demand measured using these probes, including pCBA, would be underestimated.

The authors postulated the triplet excited state of H_2O_2 as the reactive species responsible for the degradation of pCBA in addition to the •OH and direct photolysis pathways. Although there is no direct experimental evidence in the public domain on the decay of H_2O_2 excited states, Kim *et al.* advanced the idea of pCBA degradation *via* a H_2O_2 triplet state based on the observed p-CBA byproducts containing the oxygen isotope (^{18}O) atom when they used $H_2{}^{18}O_2$.

Based on their experimental results, Kim *et al.* concluded that the impact of the reaction of $(H_2O_2)^*$ on the degradation kinetics of the •OH probe compound (*e.g.* pCBA) would be more significant under the following conditions: (*a*) presence of high concentrations of •OH scavengers; (*b*) high concentration of H_2O_2 dosed to the water sample subject to •OH water background demand measurement; and (*c*) low concentration of dissolved oxygen. The higher the contribution of $(H_2O_2)^*$ to the kinetics of pCBA decay, the greater the underestimation of the •OH water background demand.

Providing the recent literature information and additional in-house investigation on p-CBA suitability as a probe for the OH radical water matrix demand determination, Trojan decided not to use this compound as a probe anymore. Further proprietary research studies conducted at Trojan resulted in adopting a reliable probe compound for OH radical water matrix demand. That compound has been used over the past 3-4 years.

UV system sizing was based on a water sample submitted to Trojan for hydroxyl radical scavenging demand determination in May 2021. The results are listed with other parameters in Table 3-1. For the final design revised RO water quality, projections were provided by Brown and Caldwell and calculations were performed by Trojan to settle on a final design scavenging value of 105,000 s^{-1}. and programmed into the PLC leaving the factory.

Table 3-1: Hydroxyl radical scavenging demand results used to support sizing

Trojan ID	Sample ID	Date Received	pH	Alkalinity (mg/L as $CaCO_3$)	UVT_{254} (%)	TOC (mg/L)	Nitrate (mg/L as NO_3^-)	Scavenging Term (s^{-1})
2035	RO Skid #1	May 12, 2021	7.64	203.16	99.3	0.31	0.65	109,000
2036	RO Skid #2	May 12, 2021	7.68	225.68	99.3	0.46	0.741	115,000
2037	RO Permeate	May 12, 2021	7.89	277.58	99.0	0.75	1.00	150,000

Additional samples were collected in June 2022, February 2023, and June 2023 the results are listed with other parameters in Table 3-2. It was observed that the water quality of the RO Permeate improved significantly over time. Finally, this led to scavenging values of 5,000, 7,500, or 15,000 s^{-1} to be used during the system performance testing. These values were chosen by Brown & Caldwell mainly to observe how the control algorithm would respond to changes in scavenging.

Table 3-2: Hydroxyl radical scavenging demand results used to support system control.

Trojan ID	Sample ID	Date Received	pH	Alkalinity (mg/L as $CaCO_3$)	UVT_{254} (%)	TOC (mg/L)	Nitrate (ppm as NO_3^-)	Scavenging Term (s^{-1})
2410	RO Permeate	June 2, 2022	6.99	151.81	98.3	0.62	0.01	49,400
2667	CHO 1&2	February 21, 2023	5.65	61.06	99.2	0.45	2.73	25,000
2786	RO Permeate	June 14, 2023	6.03	11.94	100.0	0.12	0.004	4,570

3.3 TROJAN UV/H_2O_2 SYSTEM CONTROLS

The operation of Trojan UV-Oxidation Systems for contaminant treatment is based on the calculation of an instantaneous contaminant log-reduction (LR) as a function of the fundamental contaminant kinetic parameters, system flow, UV transmittance, hydroxyl radical scavenging demand, H_2O_2 concentration and UV reactor intensity sensor values. The methodology is based on a contaminant treatment kinetic model that combines a fundamental photochemical kinetic model with an empirically validated UV dose model to accurately predict the degradation of contaminants in a UV-oxidation system (i.e. UV alone or combined with an oxidant to generate hydroxyl radicals).

Therefore, the UV system control algorithm provides a dynamically-adjusted system based upon the identified process input parameters. These include flow rate, UVT, hydroxyl radical scavenging demand, and contaminant influent and target effluent concentration (to calculate target LRs). Further, by inputting the H_2O_2 and electrical energy costs, the algorithm calculates the combination of lamp power and H_2O_2 concentration that meets the contaminant treatment objective at the lowest operating cost. Specific constraints on the limits of the system operation can also constrain the operating conditions.

The fundamental photochemical kinetic model is based upon a contaminant-specific pseudo-first order UV fluence-based reaction rate constant (k′, cm^2 /mJ) that accounts for contaminant reduction due to both UV direct photolysis and hydroxyl radical oxidation. In addition to the contaminant-specific fundamental kinetic parameters (i.e., quantum yield (Φ_C), molar absorption coefficient (ε_C) & second order hydroxyl radical rate constant $k_{C,OH}$), this fluence-based rate constant k′ is dependent upon the H_2O_2 concentration and the hydroxyl radical scavenging demand of the water ($\sum k_s[S]$ or S.T.). Typically, the scavenging demand of the water is considered to be either a constant value (based upon historical measurements) or linked to certain measurable water quality parameters. The H_2O_2 concentration is a control variable that can be monitored and adjusted together with the UV reduction equivalent dose (RED) to provide the target LR of the contaminant. The fluence-based rate constant for contaminant treatment with the UV/H_2O_2 AOP is calculated using the following equation:

$$\frac{k_c}{I_{avg.}} = k_c^{'} = \frac{\phi_c \varepsilon_c LN(10)}{U} + \frac{LN(10)\phi_{OH}\varepsilon_{H_2O_2}k_{c,OH}[H_2O_2]}{U(k_{H_2O_2,OH}[H_2O_2]+\sum k_{s,OH}[S])} \qquad \textbf{Eq. 1}$$

where,

Symbol	Description
U	Photon energy at 253.7 nm (J/einstein)
ϕ_C	Quantum Yield of contaminant at 254 nm
ϕ_{OH}	Quantum Yield of OH radical formation from hydrogen peroxide photolysis
ε_C	Molar absorption coefficient of contaminant at 254 nm, M^{-1} cm^{-1}
ε_{H2O2}	Molar absorption coefficient of hydrogen peroxide at 254 nm, M^{-1} cm^{-1}
$k_{C,OH}$	Reaction rate constant of contaminant with OH radical, M^{-1} s^{-1}
$k_{H2O2,OH}$	Reaction rate constant of H_2O_2 with OH radical, M^{-1} s^{-1}

$k_{s,OH}[S]$	Hydroxyl radical scavenging for various constituents S in the water matrix, s^{-1}

Equation 1 is provided and discussed further by Stefan (2018). Inspection of equation 1 shows that for a given contaminant and water quality (i.e., $(\sum k_S[S])$, the H_2O_2 concentration is the only independent variable.

This rate constant has the units cm^2 /mJ. The UV dose required to achieve 90% removal of a chemical pollutant (D_{10}, mJ/cm^2) is related to the fluence-based rate constant k_C' through equation (1):

$$D_{10} = Ln(10)/k_c' \qquad \textit{Eq. 2}$$

Therefore, for a given H_2O_2 concentration, a target LR (LR_t) is achieved by delivering the required UV dose i.e. the reduction equivalent dose (RED, mJ/cm^2).

$$RED_t = D_{10} \times LR_t \qquad \textit{Eq. 3}$$

The RED delivered by a UV reactor is a function of various parameters among which the water flow rate and UVT, the lamp power level, the quartz sleeve transmittance (including fouling) and the UV reactor efficiency. The flowrate and UVT are measured parameters. The lamp power level is the controlled/independent variable.

In disinfection applications, the RED for a UV reactor is calculated using a bioassay-generated validated equation in which RED is a function of UV lamp power level/UV intensity measurement, flowrate, UVT and D_{10} (i.e. the dose per LR of a microorganism or contaminant). Similarly, for UV-AOP applications, Trojan has developed a RED equation for the TrojanUVFlex200 reactor using an empirically validated computational fluid dynamics (CFD) model to relate RED to the UV intensity sensor values, flowrate, UVT, and D_{10}.

The control algorithm evaluates various combinations of lamp power and related RED and H_2O_2 dose and related D_{10}, all of which meet the contaminant LR target and selects that combination which represents the minimum operating cost.

4 METHOD

4.1 EXPERIMENTAL SET UP

4.1.1 1,4-Dioxane and NDMA Dosing

To quantitatively demonstrate the required log reduction targets of 1,4-dioxane and NDMA, the required 1,4-dioxane and NDMA concentrations required in the UV influent were calculated such that the contaminant concentrations could be accurately measured in both UV influent and UV effluent samples. Therefore, the influent contaminant concentrations needed to be high enough such that 1,4-dioxane and NDMA concentrations in the UV effluent samples were greater than the analytical method reporting limit (MRL). The analytical method employed for 1,4-dioxane analysis was EPA Method 522, which has an MRL of 0.070 µg/L. The analytical method employed for NDMA analysis was EPA Method 521, which has an MRL of 2 ng/L. Since it was recommended to avoid working at concentrations approaching the MRL, we chose a target UV effluent 1,4-dioxane concentration of ~0.35 µg/L and target UV effluent NDMA concentration of ~10 ng/L.

The 1,4-dioxane injection stock was prepared by diluting 1 g of >99.5% pure 1,4-dioxane (Chemservice N-10220-1G) in 1.0 L of distilled water to prepare a 1000 mg/L stock solution. The NDMA injection stock was prepared by diluting 600 mg of >99.5% pure NDMA (Chemservice N-12575-100mg) in 1.0 L of distilled water to prepare a 600 mg/L stock solution. Both stocks were injected using a peristaltic pump into the UV influent piping approximately 15 ft upstream of the UV reactors (and upstream of H_2O_2 injection and inline static mixer).

4.1.2 Achievement of Steady State Operation

A critical requirement is that the UV system be operating at steady state prior to collection of the UV reactor influent-effluent sample pairs. The method that was used to determine the time required to reach steady state was a tracer test with the UVT modifier Super Hume (UAS of America), which is a liquid concentrate natural organic matter. A step-down change in the UVT was made and samples were collected at specified time intervals at both the reactor influent and effluent sample ports. The reactor lamps were off during this test. The samples were analyzed on-site for UVT to determine the time required for the system to reach steady state following a change in process conditions. Then a step-up change in UVT was made by stopping the Super Hume injection and samples were collected and measured.

4.2 TEST PROCEDURE

The general procedure for each test completed was:

- Warming up the UV system/lamps;
- Setting and verifying stable system flow at the target value for each test condition;
- Entering the desired lamp sections on, lamp power level and H_2O_2 dose (for manual mode) or the 1,4-dioxane and NDMA log reduction targets for automatic mode
- Starting the pump to inject the UVT modifier (Super Hume) and/or 1,4-dioxane and NDMA;
- Waiting for steady state time to elapse;
- Recording the relevant data on a hard copy bench sheet;
- Collecting the influent and effluent sample pairs;
- Measuring hydrogen peroxide and UVT in the UV influent and UV effluent.

4.2.1 Test Matrix

Table 4-1 presents the original test matrix and summarizes the operational conditions. Test 1 and 2 were planned control tests with peroxide only and then UV only at a peak flow of 278 gpm for both tests. The UV only test (Test 2) was expected to demonstrate some NDMA treatment, but essentially no 1,4-dioxane treatment due to the requirement for hydroxyl radicals generated from the photolysis of H_2O_2. The peroxide only test (Test 1) was added to demonstrate that UV is required for treatment of 1,4-dioxane. Therefore, Test 1 could act as a negative control test for 1,4-dioxane, and therefore could provide data to judge sample collection, handling, and analysis quality control.

Test 3 was to be conducted in manual mode at the design peak flow of 278 gpm with all 2 lamp sections on at 84% BPL and the peak H_2O_2 dose of 6.5 ppm. The 84% BPL was chosen to simulate design end of lamp life and sleeve fouling conditions. UVT target was the design UVT of 96%. Test 4 conditions are identical to Test 3 except that it was to be performed on the other Flex100 reactor.

Tests 5 to 12 were to be completed in automatic mode with the design LR targets of 0.5 LR of 1,4-dioxane and 1.0 LR of NDMA. The unit costs for electrical energy and H_2O_2 were modified as discussed below. The objective of these tests was to verify that the PLC-based control program was effectively adjusting BPL and H_2O_2 dose for ambient, design, and slightly below design UVTs and flow rates.

Test 5 was to be completed in automatic mode at the design flow of 278 gpm and with 95%T water. The Scavenging Term value was set to 7500 s^{-1}. The H_2O_2 Cost was set artificially low to \$0.01/L and the electricity cost was inflated dramatically to \$10/kWh. The purpose of this was to drive the Automatic Control system to favor H_2O_2 over UV power. In other words, to minimize operating costs, the Automatic Control system would favor reducing UV power and compensating that with increasing H_2O_2 concentration in order to meet the target contaminant log reductions.

Test 6 was to be completed in automatic mode at the design flow of 278 gpm and with 97%T water. The Scavenging Term value was set to 7500 s^{-1}. The H_2O_2 cost was set artificially low to \$0.21/L and the electricity cost was inflated to \$2/kWh.

Test 7 was to be completed in automatic mode at the design flow of 278 gpm and with ambient UVT water. The Scavenging Term value was set to 7,500 s^{-1}. The H_2O_2 cost was set to \$1.21/L and the electricity cost was set to \$0.08/kWh.

Test 8 was to be completed in automatic mode at the half design flow of 139 gpm and with 95%T water. The Scavenging Term value was set to 7,500 s^{-1}. The H_2O_2 Cost was set to \$2.41/L and the electricity cost was set to \$0.08/kWh. These are the actual costs of H_2O_2 and electricity and were provided by the Chobani operators.

Test 9 was to be completed in automatic mode at the half design flow of 139 gpm and with 97%T water. The Scavenging Term value was set to 7,500 s^{-1}. The H_2O_2 cost was set to \$2.41/L and the electricity cost was set to \$0.08/kWh.

Test 10 was to be completed in automatic mode at the half design flow of 139 gpm and with ambient UVT water. The Scavenging Term value was set to 7,500 s^{-1}. The H_2O_2 cost was set to \$2.41/L and the electricity cost was set to \$0.08/kWh.

Test 11 was to be completed in automatic mode at the half design flow of 139 gpm and with ambient 97%T water. The Scavenging Term value was set to 7,500 s^{-1}. The H_2O_2 cost was set to \$2.41/L and the electricity cost was set to \$0.08/kWh.

Test 12 was to be completed in automatic mode at the maximum achievable flow of the system, which was estimated to be 417 gpm, and with ambient UVT water. The Scavenging Term value was set to 15,000 s^{-1}. The H_2O_2 cost was set artificially low to \$0.01/L and the electricity cost was inflated dramatically to $10/kWh. The purpose of this was to drive the Automatic Control system to favor H_2O_2 over UV power.

Table 4-1: Original test matrix.

Test	Mode	UV Reactor Train	Flow Rate (GPM)	Lamp Sections	Lamp Power (%)	UV Inf H_2O_2 (mg/L)	Target UVT (%)	Target Log Reduction	
								1,4-dioxane	NDMA
1	Manual	1	278	2	0	6.5	Ambient	-	-
2	Manual	1	278	2	100	0	Ambient	-	-
3	Manual	1	278	2	84	6.5	96	-	-
4	Manual	2	278	2	84	6.5	96	-	-
5	Auto	2	278	Auto	Auto	Auto	95	0.5	1
6	Auto	1	278	Auto	Auto	Auto	97	0.5	1
7	Auto	1	278	Auto	Auto	Auto	Ambient	0.5	1
8	Auto	1	139	Auto	Auto	Auto	95	0.5	1
9	Auto	1	139	Auto	Auto	Auto	Ambient	0.5	1
10	Auto	1	139	Auto	Auto	Auto	Ambient	0.5	1
11	Auto	2	139	Auto	Auto	Auto	97	0.5	1
12	Auto	2	417 (Max achievable)	Auto	Auto	Auto	Ambient	0.5	1

4.2.2 Sample Handling

Sample bottles were provided by Eurofins Laboratories. UV influent samples were collected simultaneously with the UV effluent samples, ensuring steady-state operating conditions upon any change in the test variables. Care was taken to ensure no headspace was present in the sample bottles. Separate containers were used to obtain UV influent and UV effluent samples for UVT and hydrogen peroxide for onsite analysis, with the analysis being completed by Trojan within approximately 10 minutes of sample collection. Samples were placed in coolers with ice by Brown and Caldwell staff and sent bycourier to Eurofins, with Chain of Custody procedures followed.

4.2.3 UV Transmittance (UVT)

Online UVT was measured using a Trojan Optiview™ meter which is located upstream of peroxide injection. Grab samples from the UV influent and effluent sample ports were measured using a 4cm path length quartz cell and a RealUVT™ 254nm portable photometer (RealTech Inc., Canada).

4.2.4 Hydrogen Peroxide

Hydrogen peroxide was measured using the DPD/peroxidase method described by Bader *et al.* (1988). In this procedure, hydrogen peroxide reacts with DPD reagent (Hach Company) through a reaction catalysed by the peroxidase enzyme (horseradish peroxidase, Millipore Sigma USA).

4.2.5 Hydroxyl Radical Scavenging Demand

As mentioned in section 3.2.2, Trojan routinely determines the scavenging demand of water samples at its laboratory in London, Ontario. A probe compound is added for which the rate constant for the •OH reaction is available in the published literature and was also confirmed by Trojan. The spiked water samples are irradiated to precise UV doses at 253.7nm from a UV lamp mounted in a low-pressure collimated beam apparatus. The *quasi*-parallel UV light beam is perpendicular to the water sample surface. UV fluence rate at the water surface is measured using a calibrated radiometer (International Light Technologies Inc.) and the exposure times with NIST traceable stopwatches. The sample results are used to develop a UV dose-response relationship, from which the probe degradation kinetics is calculated, and subsequently the •OH water matrix scavenging capacity is determined.

4.2.6 1,4-Dioxaneand NDMA

1,4-Dioxane and NDMA analyses were performed by Eurofins Laboratories. Chain-of-custody forms were used, and the laboratory reports were sent to Trojan. 1,4-Dioxane analysis was performed using USEPA method 522 The analytical method employed for NDMA analysis was EPA Method 521.

5 RESULTS

5.1 MIXING AND STEADY STATE

A mixing/steady state test was completed prior to the 12 performance tests. The test was completed at 138 gpm with the UV reactor off and using Super Hume as the tracer compound. At time t=0 min Super Hume was injected and samples were taken from the UV influent and UV effluent ports simultaneously at 30 second intervals and measured for UVT. After 450 seconds, the Sumer Hume injection stopped and UVT measurement continued. The test results are shown in Figure 5-1 and indicate that steady state at the UV effluent port was reached at approximately 380 seconds. Therefore, it was decided that 10 minutes was used as a steady state time for each test prior to sampling for tests run at 139 gpm. For tests run at 278 gpm and higher, 5 minutes of steady state time was used prior to sampling.

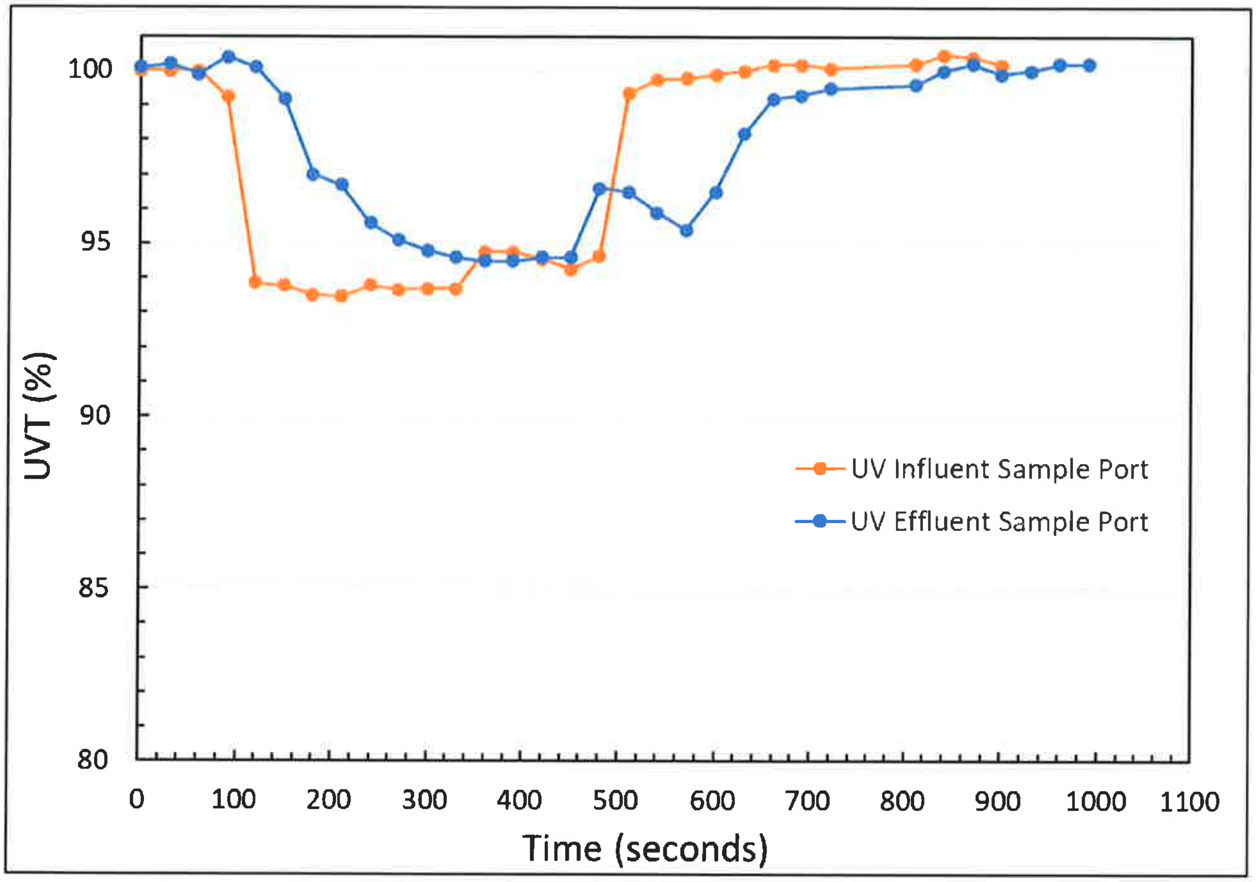

Figure 5-1: Mixing/steady state test results.

5.2 WATER QUALITY

Results for Chobani water samples sent to Trojan during the performance testing (June 28 and 29, 2023) are listed in Table 5-1. Well 37 was used for all performance tests completed. Of note are the hydroxyl radical scavenging results, which show an average value of 11,185 s^{-1} for the two samples taken during testing.

Nitrate concentrations in the submitted samples are low, which is favorable relative to high values, since nitrate photolyzes to form nitrite (a strong hydroxyl radical scavenger).

It was observed that for the sample where Super Hume was added (June 29) as expected, the UVT reduced but this also resulted in a 0.23 mg/L increase in TOC and a 7,230 s^{-1} increase in scavenging. Trojan's experience is that Super Hume generally does not have a noticeable impact on scavenging term so it is hypothesized that the June 28 sample could have gotten contaminated by some foreign material.

Table 5-1: Trojan water quality results for Chobani samples.

Sample	pH	Alkalinity (mg/L as $CaCO_3$)	UVT (%)	TOC (mg/L)	Total Iron (mg/L)	Nitrate (mg/L as NO_3^-)	Scavenging Term (s^{-1})
June 28, 2023; before Test 10	6.09	15.49	99.7	0.41	nd	0.08	7,570
June 29, 2023; before Test 6	6.05	24.45	94.2	0.64	0.02	nd	14,800

5.3 ON-SITE DATA AND MEASUREMENTS

Table 5-2 presents the important on-site measurements recorded for each test run. These include the measured flow rate, the operating train, the number of lamp sections operating and the percent lamp power level, the UV intensity sensor responses, and the target influent H_2O_2. The HMI predicted 1,4-dioxane and NDMA log reductions are also listed. Also included are key controller settings including the Fouling Factor, Scavenging Term, H_2O_2 Cost, and Electricity Cost.

To qualify the results shown in Table 5-2, the online UVT and H_2O_2 dosing must be examined. To do this, the Optiview online UVT measurements were compared to the UVT grab samples measured using the bench-top photometer (Figure 5-2, Table 5-3). Note that the UVT of the grab samples are adjusted to take into account the absorbance of the H_2O_2 present in the sample. The results are in good agreement, with the online meter reading slightly higher.

To evaluate the H_2O_2 dosing accuracy, the HMI calculated inlet H_2O_2 concentration (calculated by the HMI from the H_2O_2 pump flow rate, water flow rate, and H_2O_2 stock concentration) and measured UV influent H_2O_2 results are plotted on Figure 5-3 and tabulated in Table 5-3. Figure 5-3 shows that HMI-displayed H_2O_2 concentrations are very close at the low H_2O_2 concentration (around 1 mg/L) and slightly lower (less than 10% lower) at the higher H_2O_2 concentrations (3 to 7.5 mg/L).

Table 5-2: Tabulated data for each test completed.

						Controller Settings									HMI Predicted Log Reductions	
Test	Date	Start Time	End Time	Train	Sections On	Mode	Fouling Factor	Scavenging Term (s^{-1})	H_2O_2 Cost ($/L)	Elec. Cost ($/kWh)	Power (%)	Flow (gpm)	Sensor Intensity	H_2O_2 Setpoint (mg/L)	1,4-dioxane	NDMA
1 (Control)	27-Jun-23	17:18	17:24	1	0	Manual	0.95	5000	0.95	0.30	0	278.58	0	7.03	-	-
2 (Control)	27-Jun-23	14:41	14:47	1	2	Manual	0.95	5000	0.95	0.30	100.0	280.17	18.63	0.00	-	-
3	27-Jun-23	19:01	19:06	1	2	Manual	0.95	5000	0.95	0.30	84.0	272.57	11.78	6.35	-	-
4	28-Jun-23	11:16	11:21	2	2	Manual	0.95	5000	0.95	0.10	84.0	272.50	10.52	5.97	-	-
5	29-Jun-23	14:20	14:26	2	2	Auto	0.95	7500	0.01	10.00	34.5	279.00	3.48/ 4.59	3.54	1.27	1.21
6	29-Jun-23	11:16	11:20	1	2	Auto	0.95	7500	0.21	2.00	30.0	273.50	4.83/ 4.45	1.30	0.82	1.60
7	29-Jun-23	10:36	10:41	1	1	Auto	0.95	7500	1.21	0.08	30.0	274.98	4.96	1.30	0.79	1.56
8	28-Jun-23	18:01	18:04	1	1	Auto	0.95	7500	2.41	0.08	42.5	139.03	5.12	1.02	0.53	1.25
9	28-Jun-23	16:36	16:40	1	1	Auto	0.95	7500	2.41	0.08	30.0	141.41	4.96	0.97	1.00	2.44
10	28-Jun-23	15:31	15:35	1	1	Auto	0.95	7500	2.41	0.08	30.0	141.91	5.36	1.01	*	*
11	28-Jun-23	18:44	18:48	2	1	Auto	0.95	7500	2.41	0.08	36.5	136.86	3.66	1.07	0.62	1.55
12	29-Jun-23	14:56	15:00	2	2	Auto	0.95	15000	0.01	10.00	100.0	305.10	12.62/ 17.61	0.86	**	7.51

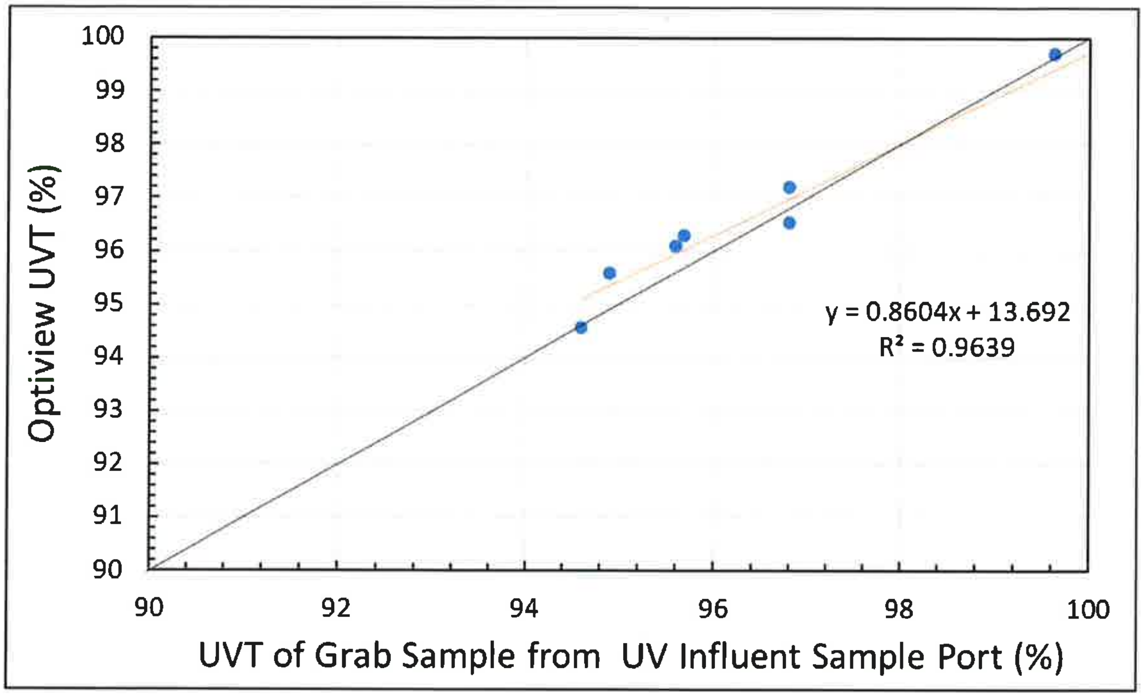

Figure 5-2: Comparison between online UVT and measured UVT of grab sample from UV Influent Port. UVT of UV Influent Port is with H2O2 absorbance subtracted.

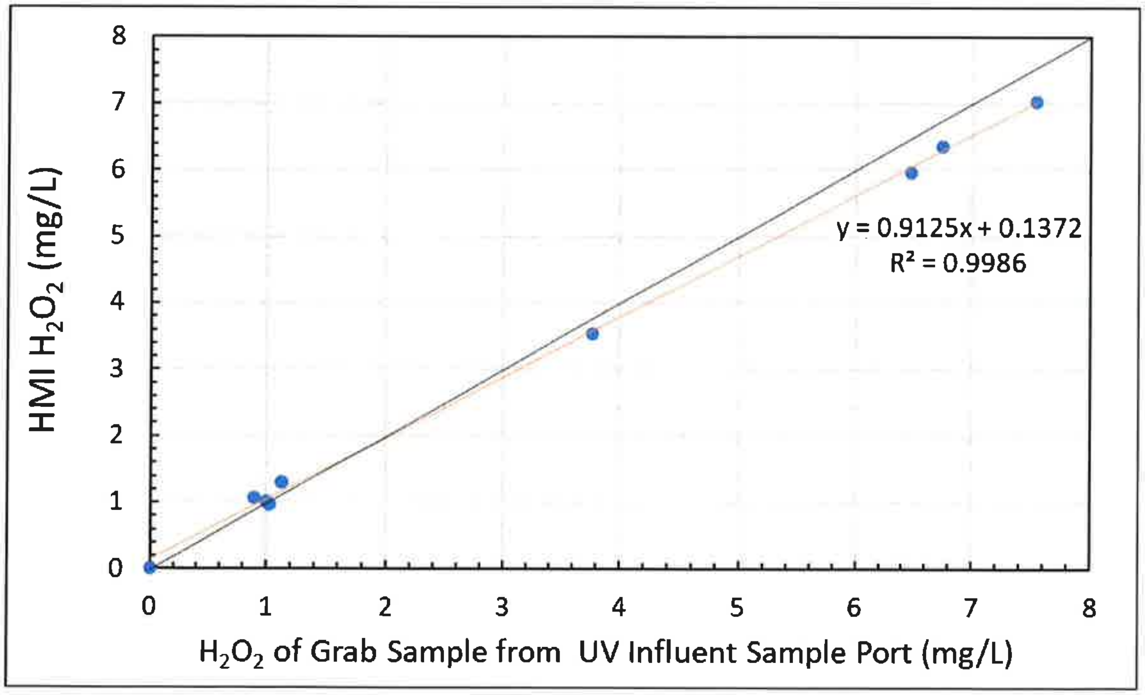

Figure 5-3: Comparison between measured and HMI H_2O_2 concentrations.

5.4 1,4-DIOXANE AND NDMA TREATMENT

The 1,4-dioxane and NDMA data reported by Eurofins are listed in Table 5-3, along with a summary of key operational data for each test. Table 5-4 provides the measured and predicted 1,4-dioxane and NDMA log reductions. For all predicted 1,4-dioxane values a scavenging term value of 7,570 s^{-1} was used. Figures 5-4 and 5-5 illustrate measured and predicted log reductions of 1,4-dioxane and NDMA, respectively. On average the measured log reductions exceed the predicted by 33% for 1,4-dioxane and 21%

For the H_2O_2 only control test (Test 1), as expected there was no reduction in NDMA or 1,4-dioxane. For the UV only control test (Test 2) there was no observed reduction in 1.4-dioxane and a high reduction of NDMA, both as expected.

Tests 3 and 4 had nearly identical operating conditions but were performed on different reactors. These tests demonstrate that the when the system was operated at the design conditions and including the simulation of end of lamp life and lamp sleeve fouling, the design targets of 1,4-dioxane (>0.5 LR) and NDMA (>1.5 LR) were exceeded. For 1,4-dioxane, the predicted log reductions could not be observed since the effluent 1,4-dioxane was below the detection limit. For NDMA, the measured log reductions exceed the predicted by 17-23%.

Test 5 was in automatic mode at a flow of 279 gpm and with 94.75%T water. The Scavenging Term was set to 7,500 s^{-1}. The H_2O_2 Cost was set artificially low to $0.01/L and the Electricity Cost was inflated dramatically to $10/kWh. The purpose of this was to drive the Automatic Control system to favor H_2O_2 over UV power. This resulted in the system operating 2 sections at 34.5% power level with an inlet H_2O_2 concentration of 3.77 mg/L. The achieved log reductions of 1,4-dioxane and NDMA were 1.51 and 2.56, respectively. The measured log reductions exceed the predicted by -7% and 40%, respectively.

Test 6 was in automatic mode at a flow of 273.5 gpm and with 96.95%T water. The Scavenging Term value was set to 7500 s^{-1}. The H_2O_2 Cost was set artificially low to $1.21/L and the Electricity Cost was inflated dramatically to $2/kWh. This resulted in the system operating 2 sections at 30% power level with an inlet H_2O_2 concentration of 1.13 mg/L. Comparing to Test 5, the lamp power level and inlet H_2O_2 concentration are lower, demonstrating that the control system was able to turn down in response to the higher influent UVT in Test 6. The achieved log reductions of 1,4-dioxane and NDMA were 1.46 and 2.98, respectively. The measured log reductions exceed the predicted by 37% and 32%, respectively.

Test 7 was in automatic mode at a flow of 274.98 gpm and with ambient UVT 99.6%T water. The Scavenging Term value was set to 7500 s^{-1}. The H_2O_2 Cost was set to $1.21/L and the Electricity Cost was set to $0.08/kWh. This resulted in the system operating 1 section at 30% power level with an inlet H_2O_2 concentration of 1.13 mg/L. Comparing to Tests 5 and 6, the number of sections operating is lower (1 vs 2) demonstrating that the control system was able to turn down in response to the higher influent UVT in Test 7. The achieved log reductions of 1,4-dioxane and NDMA were 1.57 and 2.77, respectively. The measured log reductions exceed the predicted by 54% and 32%, respectively.

Test 8 was in automatic mode at a flow of 139.03 gpm and with 94.08%T water. The Scavenging Term value was set to 7500 s^{-1}. The H_2O_2 Cost was set to $2.41/L and the Electricity Cost was set to $0.08/kWh. This resulted in the system operating 1 section at 42.5% power level with an inlet H_2O_2 concentration of 1.00 mg/L. Comparing to Test 5, the number of sections operating is lower (1 vs 2) demonstrating that the control system was able to turn down in response to the lower flow in Test 8. The achieved log reductions of 1,4-dioxane and NDMA were 0.88 and 1.81, respectively. The measured log reductions exceed the predicted by 30% and 23%, respectively.

Test 9 was in automatic mode at a flow of 141.41 gpm and with ambient UVT 99.4%T water. The test matrix called for this test to be run at 97%T but there was an issue with the Superhume dosing setup during the test run resulting in no Superhume being injected at the time of sampling. The Scavenging Term value was set to 7500 s^{-1}. The H_2O_2 Cost was set to $2.41/L and the Electricity Cost was set to $0.08/kWh. This resulted in the system operating 1 section at 30% power level with an inlet H_2O_2 concentration of 1.03 mg/L. Comparing to Test 7, the number of lamps operating and inlet H_2O_2 concentration are very similar, indicating that the system had no ability to turn down in response to the lower flow in Test 9 (i.e. the minimum lamp sections and power was used). The achieved log reductions of 1,4-dioxane and NDMA were >2.16 and 3.35, respectively. The measured log reductions exceed the predicted by >41% and 6%, respectively.

Test 10 was in automatic mode at a flow of 141.91 gpm and with ambient UVT 99.4%T water. The Scavenging Term value was set to 7500 s^{-1}. The H_2O_2 Cost was set to $2.41/L and the Electricity Cost was set to $0.08/kWh. This resulted in the system operating 1 section at 30% power level with an inlet H_2O_2 concentration of 1.01 mg/L. The achieved log reductions of 1,4-dioxane and NDMA were 2.45 and 4.00, respectively. The measured log reductions exceed the predicted by 49% and 22%, respectively.

Test 11 was in automatic mode at a flow of 136.86 gpm and with 96.59%T water. The Scavenging Term value was set to 7500 s^{-1}. The H_2O_2 Cost was set to $2.41/L and the Electricity Cost was set to $0.08/kWh. This resulted in the system operating 1 section at 36.5% power level with an inlet H_2O_2 concentration of 0.91 mg/L. The achieved log reductions of 1,4-dioxane and NDMA were 1.10 and 1.62, respectively. The measured log reductions exceed the predicted by 37% and -7%, respectively.

Test 12 was in automatic mode at a flow of 305.1 gpm and with ambient UVT 99.9%T water. The Scavenging Term value was set to 15000 s^{-1}. The H_2O_2 Cost was set artificially low to $0.01/L and the Electricity Cost was inflated dramatically to $10/kWh. However, there were issues with the H_2O_2 dosing pump or this test and the system got a no flow alarm from the H_2O_2 dosing flowmeter. This resulted in the system putting both sections on at 100% power level. Despite the H_2O_2 flow meter recording no flow, H_2O_2 concentration at the inlet was measured at 3.86 mg/L average value. The achieved log reductions of NDMA was >3.22 (1,4-dioxane was not measured). The predicted NDMA log reduction was 9.34.

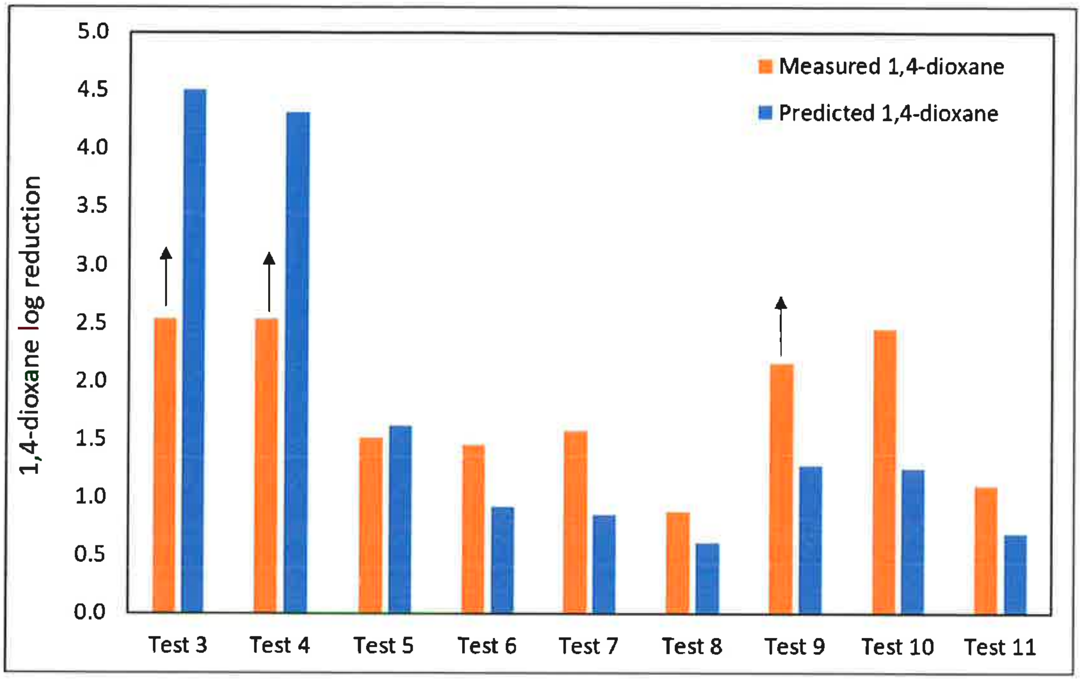

Figure 5-4: Comparison between measured and predicted 1,4-dioxane log reductions. Arrows indicate that the measured effluent 1,4-dioxane concentration was below the detection limit.

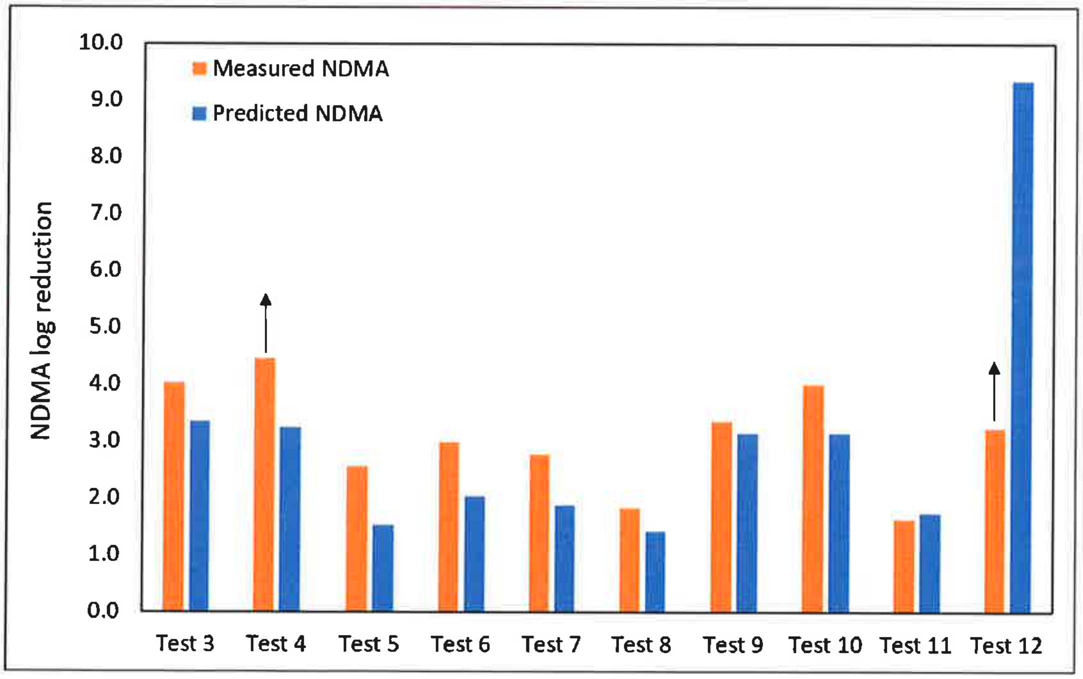

Figure 5-5: Comparison between measured and predicted NDMA log reductions. Arrows indicate that the measured effluent NDMA concentration was below the detection limit.

Table 5-3: Tabulated data for each test completed.

						UVT (%)		H_2O_2 (mg/L)		1,4-dioxane (µg/L)		NDMA (µg/L)	
Test	Mode	Train	Sections On	Power (%)	Flow (gpm)	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
1 (Control)	Manual	1	0	0	278.58	99.62	99.70	7.54	7.68	1.2	1.3	300	340
						99.35	99.80	7.54	7.68	1.3	1.2	320	310
2 (Control)	Manual	1	2	100	280.17	100.26	100.30	0.00	0.00	0.87	0.68	1700	0.36
						100.47	99.60	0.01	0.00	1.0	0.72	1400	<0.30
3	Manual	1	2	84	272.57	95.7	98.7	6.72	4.37	11.00	<0.032	8300	0.62
						95.6	98.6	6.77	4.32	11.00	<0.032	8700	1.00
4	Manual	2	2	84	272.5	95.60	98.60	7.10	3.98	11.00	<0.032	8000	<0.30
						95.60	98.70	5.86	3.45	11.00	<0.032	8600	<0.30
5	Auto	2	2	34.5	279	94.90	96.50	3.79	2.93	4.3	0.13	910	3
						94.60	95.90	3.74	2.88	4.2	0.13	1100	2.6
6	Auto	1	2	30	273.5	96.8	97.7	1.18	0.92	6.3	0.077	1300	1.5
						97.1	97.2	1.08	1.02	6.5	0.37	1200	1.1
7	Auto	1	1	30	274.98	100	100	1.09	1.04	4.8	0.12	760	1.5
						100	100	1.17	0.96	4.9	0.14	780	1.1
8	Auto	1	1	42.5	139.03	94.60	95.80	1.00	0.85	3.1	0.38	690	2.7
						95.00	95.70	1.00	0.84	3.3	0.47	980	23
9	Auto	1	1	30	141.41	99.2	99.0	1.04	0.86	6.0	<0.032	1400	0.82
						99.6	99.5	1.02	0.76	3.3	<0.032	1200	0.35
10	Auto	1	1	30	141.91	99.30	99.80	1.05	0.58	18	0.057	11000	1.2
						99.50	100.00	0.96	0.58	17	0.068	12000	1.1
11	Auto	2	1	36.5	136.86	96.68	97.60	0.90	0.83	3.6	0.34	850	22
						96.50	97.60	0.92	0.81	4	0.26	850	19
12	Auto	2	2	100	305.1	99.90	100.00	1.87	0.86	N/A	N/A	500	<0.30
						99.90	99.90	5.54	1.76			490	<0.30

Table 5-4: Measured and predicted log reductions for 1,4-dioxane and NDMA

								1,4-dioxane (µg/L)		NDMA (µg/L)	
Test	Mode	Train	Sections On	Power (%)	Flow (gpm)	ROP UVT (%)	Inlet H_2O_2 (mg/L)	Measured LR	Predicted LR	Measured LR	Predicted LR
3	Manual	1	2	84	272.57	96.3	6.75	>2.54	4.51	4.02	3.34
4	Manual	2	2	84	272.5	96.11	6.48	>2.54	4.31	>4.44	3.24
5	Auto	2	2	34.5	279	95.6	3.77	1.51	1.62	2.56	1.52
6	Auto	1	2	30	273.5	97.2	1.13	1.46	0.92	2.98	2.03
7	Auto	1	1	30	274.98	99.75	1.13	1.57	0.85	2.77	1.88
8	Auto	1	1	42.5	139.03	94.92	1.00	0.88	0.61	1.81	1.41
9	Auto	1	1	30	141.41	99.53	1.03	>2.16	1.27	3.35	3.14
10	Auto	1	1	30	141.91	99.53	1.01	2.45	1.25	4.00	3.13
11	Auto	2	1	36.5	136.86	96.76	0.91	1.10	0.69	1.62	1.74
12	Auto	2	2	100	305.1	99.90	NA	NA	NA	>3.22	9.34

6 CONCLUSIONS & RECOMMENDATIONS

This report documents the on-site performance tests for the TrojanUVFlex100 AOP system installed at the Chobani factory in Twin Fall, Idaho for the treatment of 1,4-dioxane and NDMA. Twelve tests were completed at flow rates ranging from 136 to 301 gpm, background water UVTs ranging from 94.9% to 99.9%, lamp power settings ranging from 30 to 100% with 1 or 2 lamp sections on, and UV influent H_2O_2 concentrations ranging from 0.91 mg/L to 6.75 mg/L.

For H_2O_2, the PLC-calculated concentrations were on average slightly lower than the measured values. Additionally, the online UVT meter was in good agreement with grab sample UVT measurements.

Based on the Performance Test results, and water samples tested to date, it is recommended to operate the system with an entered scavenging term value of 10,000 s^{-1}. As variability in the scavenging term has been observed, it is recommended that representative water samples be sent quarterly to Trojan for hydroxyl radical scavenging term evaluation.

Overall, the TrojanUVFlex100 AOP performance test results described in this report demonstrate that the system is adequately designed to meet and exceed the guaranteed 1,4-dioxane and NDMA treatment. The data presented has also shown that select calculations used for the automatic control system are accurate (and in fact conservative) based on measured results, and this provides confidence that the system can reliably operate over a range of flows, water qualities and treatment targets.

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